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POWER WIRING DIAGRAMS

A HANDBOOK OF CONNECTION DIAGRAMS OF CONTROL AND PROTECTIVE SYSTEMS FOR INDUSTRIAL PLANTS

BY

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PREFACE

IN this edition the text and tables have been revised and reset The whole of the diagrams have been carefully revised and a number of new ones have been added

The author wishes to take this opportunity of thanking his colleagues and a number of correspondents for kindly drawing his attention to inaccuracies in some of the diagrams of the first edition.

A T. D.

PREFACE TO THE FIRST EDITION

THIS book is intended for engineers and others associated with the application of electric power to industrial plants Its aim is to supply detail diagrams of connections for all classes of standardized control apparatus (traction control apparatus excepted) in use with continuous-current and alternating-current machines, transformers, etc

As far as possible the diagrams have been drawn to be *representative* of the actual control apparatus to which they refer, and thus differ from the elementary diagrams usually found in text-books. In certain cases, however, a detailed diagram has been supplemented by a schematic diagram in order to facilitate the tracing of the circuits To obtain uniformity throughout and to facilitate the reading of the diagrams conventional signs (some of which are in general use) have been adopted to represent certain classes of apparatus and machines.

In diagrams relating to connections of instrument transformers a knowledge of the instantaneous polarity is important, and, in the present volume, an attempt has been made to indicate the terminals, of primary and secondary windings, at which the direction of current is the same With the ordinary convention of polarity, these terminals, for a given transformer, will have *opposite* polarities

During the preparation of this work the author has received considerable assistance from several manufacturers, who have generously supplied him with data, drawings, photographs and blocks relating to their control apparatus Acknowledgments are made throughout the text, and the author desires especially to thank: The British Thomson-Houston Co, The Igranic Electric Co, The Metropolitian-Vickers Electrical Co, Messrs Brown-Boveri & Co, Messrs. Bruce Peebles & Co, Messrs Ferranti, The General Electric Co, Messrs George Ellison, The Chloride Electrical Storage Co, Messrs. W T Henley's Telegraph Works Co, The Macintosh Cable Co.

Acknowledgments are due to the Council of the Institution of Electrical Engineers and the Board of Directors of the American Institute of Electrical Engineers for permission to include extracts from the Wiring and Standardization Rules respectively of these Institutions

The author wishes to take this opportunity of thanking his colleague—Dr A W. Ashton, M.I.E.E.—for many suggestions and criticisms during the preparation of the work

A. T D

LONDON, 1917.

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SECTION 9

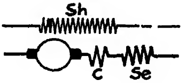
LIST OF TABLES

LIST OF ABBREVIATIONS

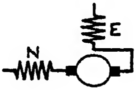
Alternating current	A C
Amperes	Amp
Direct current	D C
Double pole	D P
Double throw	D.T
Electro-motive force	E M F
Horse-power	H P.
Kilowatt	*kW.*
Single pole	S P
Single throw	S T
Triple pole	T P
Volt-amperes	VA.

CONVENTIONAL SIGNS ADOPTED IN THE DIAGRAMS

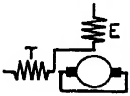
MACHINES



Direct-current motor or generator C, commutating-pole winding, Se, series winding, Sh, shunt winding



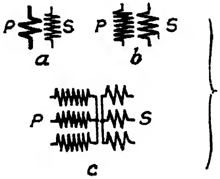
Single-phase series motor E, exciting winding, N, neutralizing (or compensating) winding



Single-phase repulsion motor E, exciting winding, T, transformer (or " energy ") winding

TRANSFORMERS

Single-phase power transformer.



Instrument transformers.

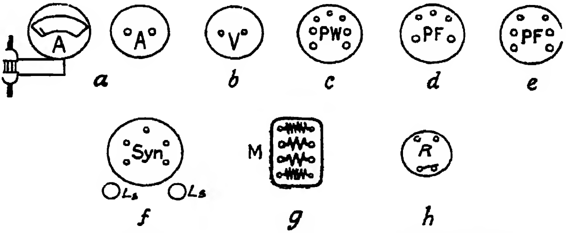
a, current transformer

b, single-phase potential transformer.

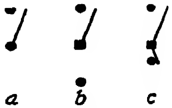
c, three-phase potential transformer

Note—*P* denotes the primary winding, *S* denotes the secondary winding.

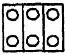
INSTRUMENTS



a, Ammeter, *b*, voltmeter; *c*, polyphase wattmeter, *d*, power-factor meter with one current and two potential coils, *e*, power-factor meter with two current coils and one potential coil, *f*, synchroscope, *Ls*, synchronizing lamps, *g*, polyphase watt-hour meter, *h*, relay



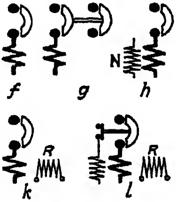
Lever switches *a*, single-pole, single throw; *b*, single-pole, double throw, *c*, single-pole field discharge switch.



Triple-pole oil switch

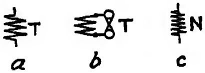
Push buttons *d*, circuit closing, *e*, circuit opening.

4-point potential plug receptacle.

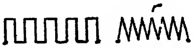
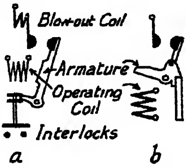
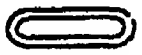


Circuit breakers *f*, single-pole maximum; *g*, double-pole (interlocked) maximum; *h*, maximum and low voltage, *k*, maximum and reverse, *l*, maximum and reverse with shunt trip and auxiliary switch.

Fuse.



Trip coils (for oil switches) *a*, instantaneous trip; *b*, trip coil with time limit fuse, *c*, low-voltage release.

	Resistances, non-inductive and inductive.
	Field rheostats
	Starting rheostat for direct current motor
	Contactors *a*, shunt-operated type, with interlocks, *b*, series lock-out type.
	Blow-out coil of controller

SECTION 1

Direct-current Motors and Control Apparatus

Internal and external connections of compound-wound, commutating-pole, motors for reversible rotation—Hand-operated starting rheostats, switches and controllers for D.C. motors—Motor control panels—Printing press controllers—Automatic controllers for machine tools, motor-driven pumps and printing machinery—Controllers for electric cranes—Wiring for overhead travelling cranes—Electric lift controllers.

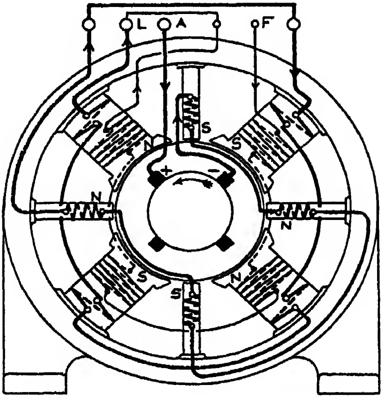


Fig. 1—Internal connections of compound-wound, commutating-pole, motor with retrogressive armature winding Rotation counter-clockwise.

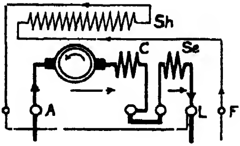


Fig 2

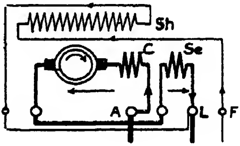


Fig 3

Schematic diagrams for motor of Fig 1 showing external connections necessary to give counter-clockwise (Fig 2) and clockwise (Fig 3) rotation

Terminals A and F are connected to corresponding terminals of starting rheostat terminal L is connected to negative line (*see* Figs 4, 5 *et seq*)

Classification of Hand-operated Starters for D.C. Motors.—(1) *Face-plate type starters*, consisting of starting switch and rheostat assembled together, are largely used for shunt- and compound-wound motors up to about 50–75 h.p. where the conditions of service do not require frequent starting The starters are usually fitted with no-volt and overload releases

(2) *Multiple-switch starters*—consisting of a number of mechanically interlocked switches assembled with rheostats in a common frame (*see* Figs 216, 219; pp 177, 178)—are used for starting large motors (up to 1,000 h.p.) The starters are usually fitted with no-volt and overload releases

(3) *Lever starting switches*—consisting of a multi-contact lever switch, of either the single-blade or double-blade type (*see* Fig 215, p 176)—with external rheostat are used for starting large motors The switches are designed for mounting on switchboard panels, and are provided with from 4–9 contact points. This type of starter is not fitted with automatic releases

(4) *Drum-type controllers*—with either self-contained or external rheostat, and with or without automatic devices—are used under service conditions for which other types of starters would be unsuitable

Controllers for shunt- and compound-wound motors up to 100 h p (550 volts) can be obtained with automatic devices—in the form of an electrically-operated circuit breaker and overload relay—which can be interlocked so as to render the starter completely foolproof These controllers can be arranged for starting, reversing and speed regulation (by means of resistance in shunt field circuit) The controller, circuit breaker, overload relay, starting and regulating resistances are self-contained in a common frame

Controllers for heavy duty are not provided with automatic features Special controllers have been developed for cranes (*see* p 27) to provide for slow motion hoisting and lowering, dynamic braking, etc

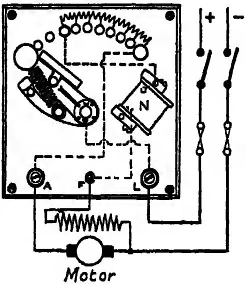


FIG. 4.

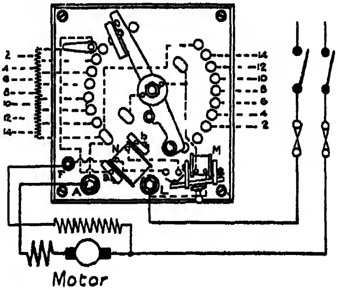


FIG. 5.

Connections of starting rheostats for shunt- and compound-wound motors

The rheostat shown in Fig 4 is of the type used with small motors . it is fitted with a no-volt release, *N*.

The rheostat shown in Fig 5 has a double set of contacts and is fitted with no-volt and overload releases (*N* and *M* respectively). Larger rheostats are fitted with renewable segmental contacts and a short-circuiting brush as shown in Fig 6.

With each form of rheostat provision is made for obtaining a full field on the motor when the switch lever is in the "running" position. Thus, in the above rheostats, the connection from the first resistance contact to the no-volt coil is connected to the pole-pieces of the release magnet and when the switch lever is in the running position a direct path from terminal *L* to *F via* the no-volt coil is established In the rheostat shown in Fig 6 a special contact button and an auxiliary brush on the switch lever are provided

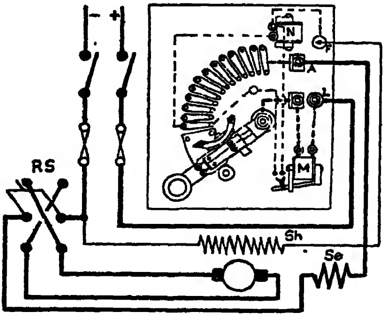


Fig. 6.—Connections of starting rheostat and reversing switch (*RS*) for reversible compound-wound motor.

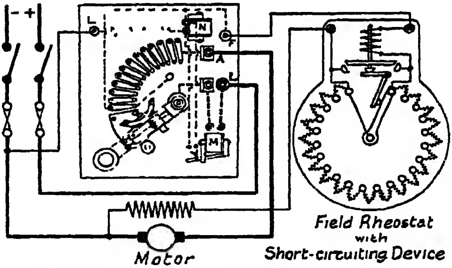


Fig. 7.—Connections of starting and field rheostats for adjustable speed motor.

The field rheostat is fitted with the B T -H safety short-circuiting switch (illustrated in Fig. 213, p 175) for preventing the motor being started with weak field The switch is opened by moving the rheostat handle to "all resistance out" position, and is held open by a solenoid connected in series with the shunt field. The solenoid, when excited with the maximum field current, is incapable of opening the short-circuiting switch, but it can hold this switch open (after the plunger has been lifted) with the minimum field current

Note.—The no-volt coil of starting rheostat is separately excited

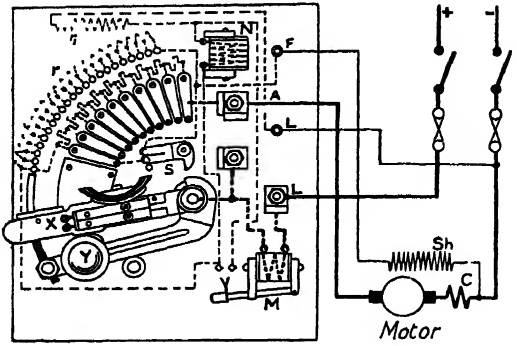


Fig 8.—Connections of combined starting and regulating rheostat for adjustable-speed motor [Igranic Electric Co]

This rheostat is designed so that resistance can only be inserted in the shunt field circuit *after* the switch lever has been moved to the running position

The contacts for field regulation are arranged concentrically with the main contacts, and connection with both sets of contacts is made by means of a double switch lever *X*, *Y* The arm *X* is fitted with main and short-circuiting brushes and a return spring the arm *Y* is fitted with a contact brush for the contacts of the field regulating resistance, *r*, and a handle

The starting resistance is cut out by moving both arms (by means of the handle on *Y*) to the running position when *X* will be retained by the no-volt magnet, *N* During starting the interlocking switch *S* is maintained in the position shown in Fig 8 by a spring, thus short-circuiting the field resistance *r* When *X* is in the running position this switch is opened and resistance can be inserted in the field circuit by moving *Y* backwards, the arm remaining in any position

The arms *X*, *Y* are mechanically interlocked so that any attempt to move *Y* to the "off" position will release *X* and stop the motor.

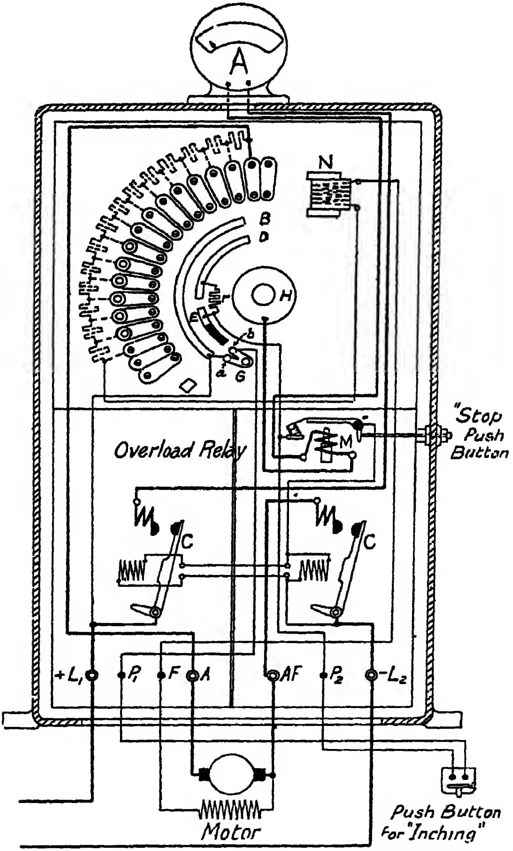


FIG 9.—Connections of Igranic "Conspede" panel—arranged for bush button "inching"—for shunt motor. [Igranic Electric Co] (For description see p 9)

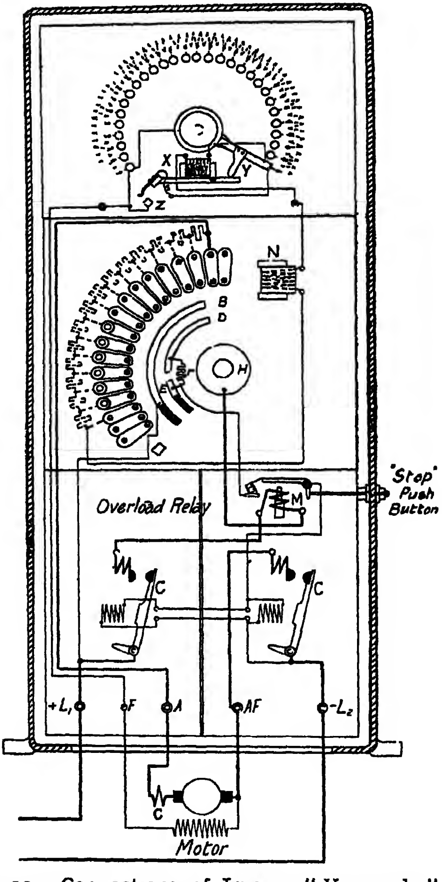


Fig. 10—Connections of Igranic "Varispede" panel for adjustable speed motor. (For description *see* p. 9)

Igranic "Conspede" and "Varispede" Control Panels [Figs 9, 10, and 215 (p. 176)] are designed respectively for constant speed and adjustable speed motors. The "Conspede" panel (Fig 9) is equipped with an electrically operated D P circuit breaker, *C*, a starting rheostat—with no-volt release, *N*—and an overload relay, *M*. The additional equipment for the "Varispede" panel consists of an interlocked field rheostat.

The starting switch is of the heavy-duty type with a main brush, bridging from centre-plate *H* to the main contact segments, and an auxiliary brush which bridges segments *B*, *D* , *B*, *E* The first movement of the switch lever to start the motor establishes a connection between *B* and *E* and completes the operating-coil circuit of the circuit breaker. Further movement of the lever inserts a resistance *r* in this circuit, in which are also included the auxiliary contacts of the overload relay. The operation of the relay opens the motor circuit at the circuit breaker, and the resistance *r* prevents the circuit breaker reclosing unless the switch lever is returned to the starting position.

When "inching" is required, the starter is fitted with an auxiliary switch, *G* (Fig. 9), and two contact studs *a*, *b*. These studs are short-circuited (by *G*) when the switch lever is in the "off" position, but are open-circuited when the lever is moved to start the motor. Thus, with the starter in the "off" position, the circuit breaker may be closed by pressing the "inching" push button, but it will open as soon as the button is released or if the switch lever is moved

The field rheostat for the "Varispede" panel is fitted with an interlock (*see* Fig 10) which prevents the motor being started with a weak field. The interlock consists of an electro-magnet, *X*, the armature of which, together with contact, *Z*, short-circuits the field rheostat when the motor is stopped The electro-magnet is connected in series with the shunt field and is designed so that the armature cannot be lifted when the coil is excited by the field current, although, when lifted, the armature will be retained when the minimum field current is passing through the coil. The short circuit is removed from the rheostat by moving the contact arm to the "all out" position, which causes a projection, *Y*, to lift the armature

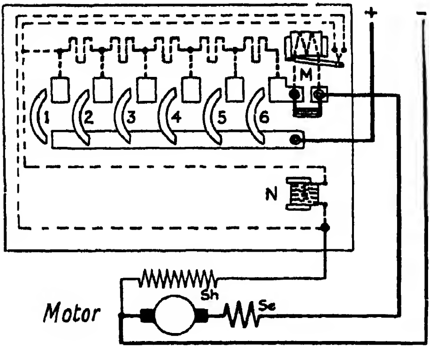


FIG. 11.— Connections of multiple switch starter with no-volt (*N*) and overload (*M*) releases [Igranic Electric Co.].

The switches can only be closed in the order given, the last switch (No 6) being retained by the no-volt release magnet *N*. *See* p. 177 for illustration of starter

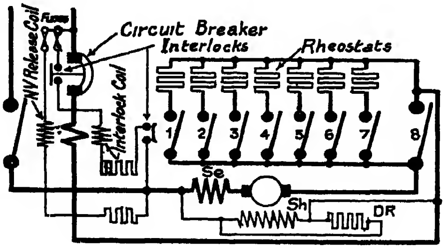


FIG 12 —Connections of multiple switch starter with interlocked circuit breaker [General Electric Co]

The starter, which is illustrated in Fig. 219 (p 178), consists of a number of lever switches which are mechanically

interlocked—by a locking bar—so that they can only be closed in the order given. The circuit breaker is fitted with overload, no-volt and interlocking coils; the interlock coil, when excited, preventing the circuit breaker being closed. The interlocking contacts on starter are only open when all the starting switches are open. Thus the circuit breaker and starter are interlocked so that it is impossible for the former to be closed with the starter partially "on"

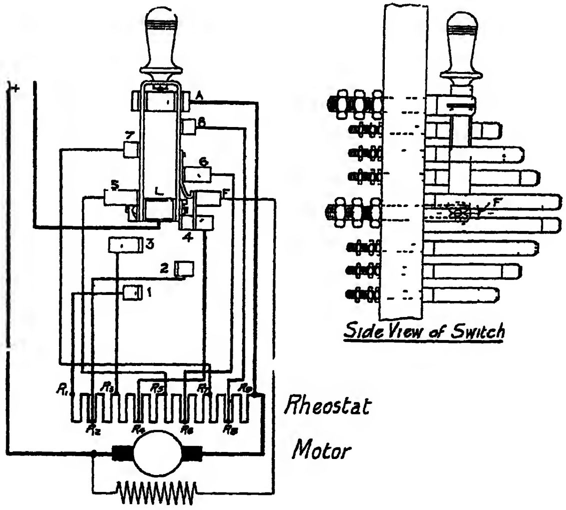


FIG 13 —Connections of 9-point lever starting switch [B T -H Co]

The switch is provided with a contact, *F*, for the field circuit so that a full field is obtained throughout the starting period

See Fig 214, p 176, for illustration of 4-point switch

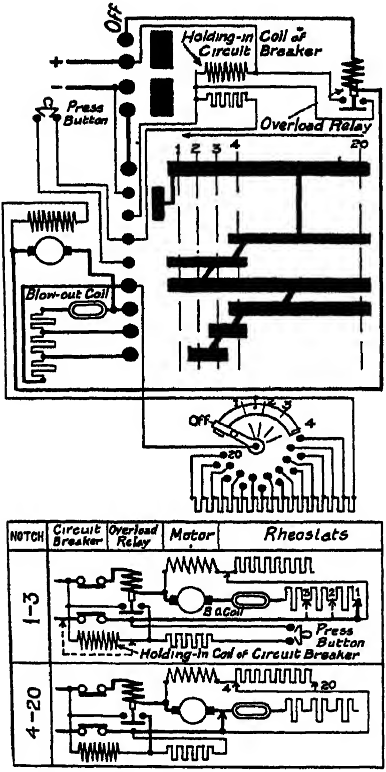


FIG 14.—Connections, development and combinations of non-reversing controller—with electrically-operated circuit breaker and overload relay—for shunt motor [Metropolitan-Vickers Elec Co]

The controller is arranged for starting and regulating

the speed of the motor, the speed regulation being obtained by inserting resistance in the shunt field circuit. The D P. circuit breaker is closed by pressing the button and moving controller cylinder to the first notch. Observe that the segment for exciting the operating coil is located between the " off " position and first notch, but that, on the first notch, the push button and series resistance are inserted in the circuit Thus, if the button is not pressed *before* the cylinder is moved to notch 1, the circuit breaker cannot remain closed. Also, if the button is released on notch 1, 2, or 3 the circuit breaker will be opened. Moreover, should an overload occur during starting the circuit breaker will be opened by the action of the overload relay In each case the controller cylinder must be returned to the " off " position before the circuit breaker can be re-closed

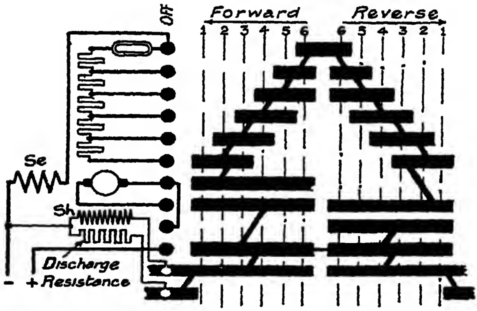


FIG 15 —Connections and development of reversing controller for compound motor [General Electric Co.].

The controller is arranged for breaking the shunt-field circuit of the motor, a non-inductive discharge resistance being connected in parallel with the field winding immediately before the circuit is opened

Automatic Control Systems for Direct-current Motors.—The methods available for automatically controlling the rate at which the starting resistance is cut out are —(1) time limit, (2) current limit, (3) counter-E M F limit.

With the first method the starting switch is usually operated by a solenoid, the motion being retarded by a dashpot The duration of the starting period can be altered by adjusting screws in the dashpot Starters of this type have been developed principally by the Igranic Electric Co and examples are illustrated in Figs 217, 221, 222 (pp 177–180)

The second and third methods require the use of contactors for cutting out the sections of the starting rheostat, the operation of the contactors being dependent on either the current input to the motor or the E.M F. at its terminals.

With the **current-limit method** two systems of operation are available, viz , (*a*) the *series relay system*, in which the operating coils of the contactors are shunt wound and are excited by means of auxiliary contacts on series relays connected in the motor circuit , (*b*) the *series lock-out system*, in which series-wound contactors are used for the accelerating points, special features being incorporated into the design so that a contactor can only close provided that the current is *within* certain limits, e g currents above the maximum limit will cause the contactor to be held open or locked out This system possesses all the advantages of the series-relay system, with the additional advantages of simpler wiring and fewer parts

An example of a starter in which series lock-out contactors are used is illustrated in Fig. 223, p 181.

With the **counter-E.M F. limit method**, the operating coils of the contactors are shunt wound and are connected in parallel across the motor terminals, the contactors being adjusted to close at different voltages This method has the disadvantage that the operation of the contactors is affected by variations in the line voltage It is satisfactory for use with small shunt and compound motors which do not require more than one or two resistance steps For larger motors a combination of the current-limit and counter-E M F method is sometimes used.

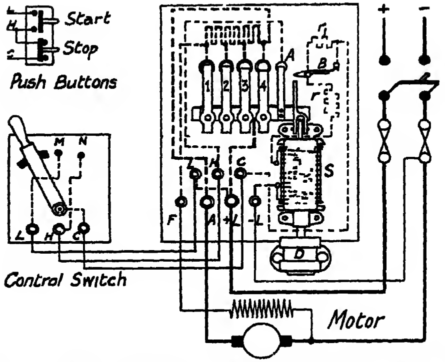


FIG 16.—Connections of Igranic multiple-finger self-acting starter.

The fingers are actuated by a shaft which is operated by the plunger of solenoid S, a time limit being introduced by the dashpot D. Finger A maintains the circuit of solenoid after the "start" button has been released, and switch B inserts resistance r_1 in this circuit when the plunger completes its stroke

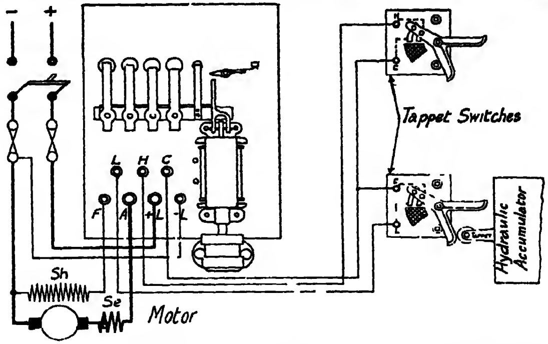


FIG 17—Connections of Igranic multiple-finger self-acting starter with tappet switches for controlling motor-driven pump working on hydraulic accumulator

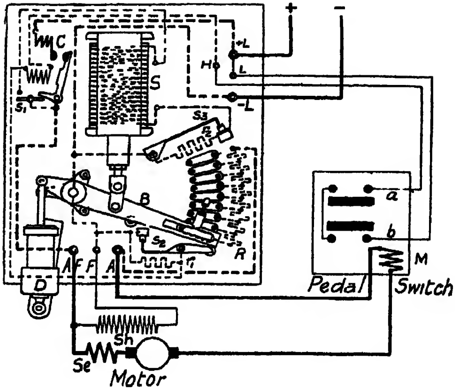


FIG. 18 —Connections of Igranic self-acting starter with pedal switch for controlling capstan motor.

The starter (*see* p 179 for illustration) consists of a pivoted switch lever *B*, which is moved over a set of contacts (to which the starting resistance *R*, is connected) by the plunger of solenoid *S*, the rate of movement being controlled by an oil dashpot *D* The motor circuit is closed and opened by the contactor *C*, so that no arcing occurs at switch lever contacts In the present instance the contactor is controlled by a pedal switch.

When connection between terminals *L* and *H* is established by the control switch, the operating coil of contactor *C* is excited The contactor will close provided that resistance r_1 is short-circuited by switch s_2 (i e. the switch lever, *B*, must be in its lowest position, with all resistance in motor circuit) When contactor closes, the solenoid *S* is excited by means of auxiliary switch s_1. The starting resistance *R* is then cut out automatically and a resistance, r_2, is inserted in series with solenoid when plunger reaches the end of its stroke

The pedal switch possesses special features It consists of two sets of contacts, *a*, *b*. The upper contacts, *a*, are closed by depressing the pedal, and the lower contacts, *b*, are normally held closed by a detent which is tripped by the coil *M* when an overload occurs. These contacts can only be reset by releasing the pedal Thus the motor circuit cannot be kept closed while an overload exists

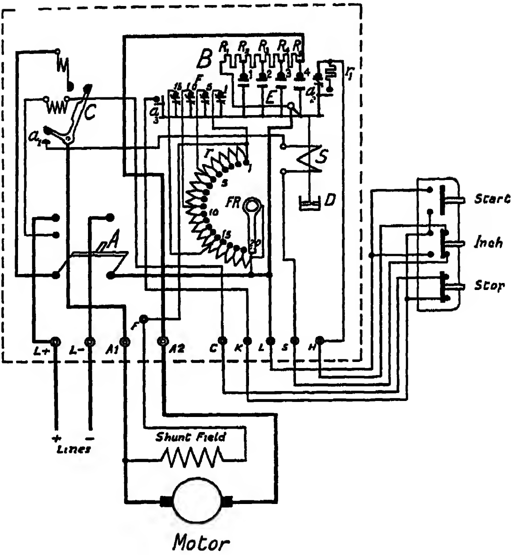


FIG 19—Connections of Ingranic Universal Control Panel (*See* also Fig 222, p 180)

The panel is arranged for push-button control and is equipped with a D P isolating switch, *A*, an automatic, multiple finger starter, *B*, a contractor, *C*, with magnetic blow-out, and a field rheostat, *FR*

The main fingers, *E*, of the starter cut out the starting rheostat and the auxiliary (circuit opening) fingers, *F*, cut in the field rheostat in four steps Both sets of fingers are actuated by a solenoid, *S*, and the duration of the starting period is controlled by an oil dashpot, *D* The solenoid is controlled by an auxiliary switch, a_1, on the contactor and the circuit opening contacts of the "inch" push button A resistance, r_1, is inserted, by auxiliary switch a_2, upon the completion of the starting operations

When the "inch" button is pressed, the contactor closes, but the automatic starter is inoperative Upon the release of this button the contactor opens Under normal starting an auxiliary switch, a_3, closes as soon as the solenoid is excited and establishes a retaining circuit for the operating coil of contactor independently of the contacts of the "start" button

The operating speed is set by the field rheostat, and every time the motor is started it will, automatically, run up to this predetermined speed

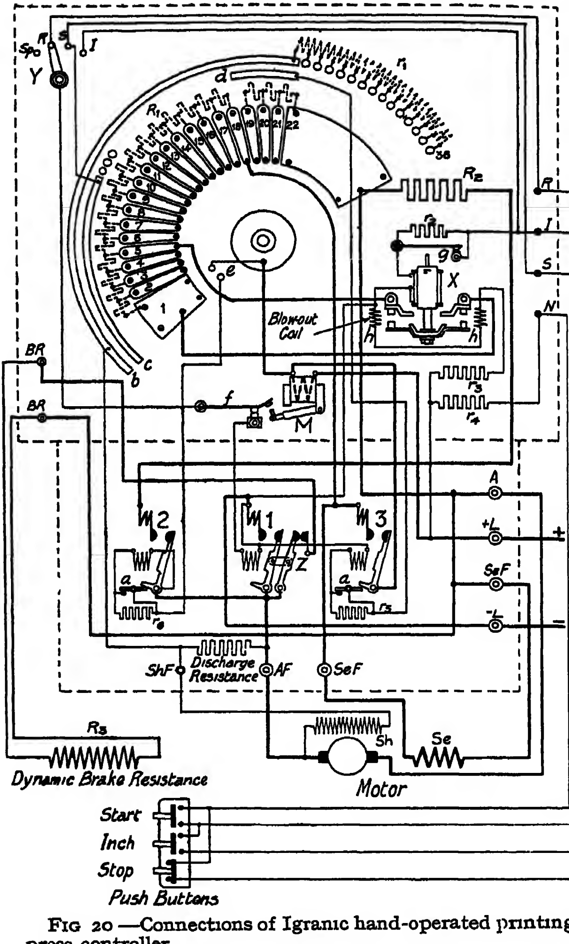


FIG 20 —Connections of Igranic hand-operated printing press controller

The controller shown in Fig. 20 is designed for controlling motors driving rotary printing presses. Provision is made for —(1) very slow starting, (2) running at very slow ("crawling") speeds[1] while machine is being prepared for printing, (3) "inching," (4) uniform acceleration of press up to printing speed, (5) rapid stopping.

The upper panel is equipped with a hand-operated face-plate type controller; a control switch, Y; a solenoid-operated "inching" switch, X, provided with magnetic blow-out coils, h; and an overload release, M. The switch lever is not fitted with a return spring and, consequently, remains in any position in which it may be left It is fitted with main and auxiliary brushes—for connecting the centre contact-plate with the various segments—and also a contact for short-circuiting the buttons e when the lever occupies the first position (i e. on segment 1).

The lower panel is equipped with three contactors, of which one (No. 1) is fitted with a switch Z, which is closed only when the contactor is open.

The switch Y on the upper panel is retained on contact R by a spring and this switch, together with the push buttons, form alternative control stations.

Assuming the switch lever to be on segment No. 1 the motor is started either by moving switch Y to contact S or by pressing the "start" button, each operation short-circuiting the resistance r_4, which is connected in the operating-coil circuit of No 1 contactor. When this contactor closes, its control circuit is maintained through the "stop" button, the control switch Y and the auxiliary contacts of the overload release M The closing of No 1 contactor automatically closes No. 2. We then have resistance R_2 connected in parallel with the armature of motor, in series with which are connected the series field and the resistance R_1. Moving the switch lever clockwise, first opens contactor No. 2 and then cuts out resistance (R_1) from the motor circuit, all resistance being cut out at segment 18 Further movement of the switch lever increases the speed by connecting resistance in parallel with the series field—by means of contactor 3—and cutting-out this resistance until the field winding is short-circuited The series field is then cut out and resistance, r_1, is inserted in the shunt field circuit

The motor is stopped either by pressing the "stop" button or by moving the control switch to contact Sp, each operation opening contactor No. 1 and connecting the braking resistance, R_3, across the armature.

[1] The "crawling" speeds required may be of the order of 5 per cent of the maximum speed of the press

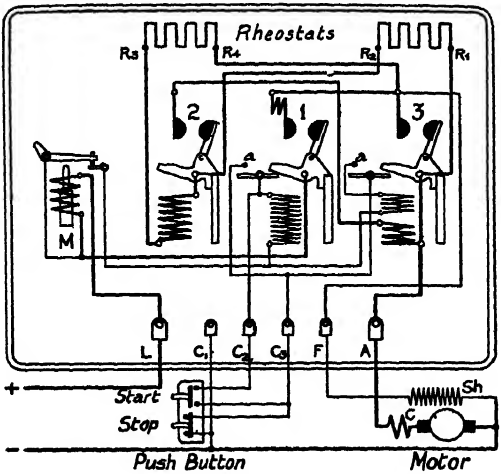


FIG 21.—Connections of B T.-H (Type SMC) automatic starter with single-coil series lock-out contactors.[1]

The starter is illustrated on page 181 It consists of three contactors and an overload relay *M*. Contactor 1 is closed by pressing the "start" push button, and the control circuit is maintained, after the button is released, by auxiliary switch *a*. Contactors 2 and 3 are of the series lock-out type and close automatically when the motor current decreases to a predetermined value Contactor 3 is retained in the closed position by a shunt coil which is excited as soon as the contactor closes by an auxiliary switch *a* The exciting current for contactors 1 and 3 passes through the "stop" button and the auxiliary contacts of the overload relay These contactors are, therefore, opened—and the motor stopped—either by pressing the "stop" button or by the action of the overload relay. The motor can only be re-started by pressing the "start" button.

[1] The contactors are illustrated and described in *Industrial Motor Control*, pp 63–66.

For reversing equipments, the above starter is used in conjunction with a hand-operated controller, which is arranged as a reversing switch (*see* Fig 23).

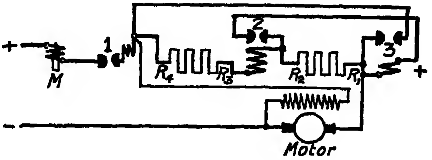


FIG 22.—Schematic representation of main-circuit connections for Fig 21.

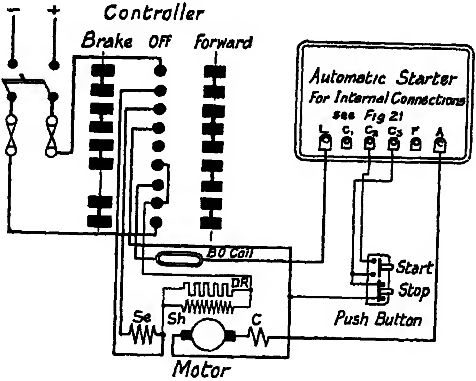


FIG. 23—Connections of B T -H (Type SMC) automatic starter with push button control and controller for reversible motor.

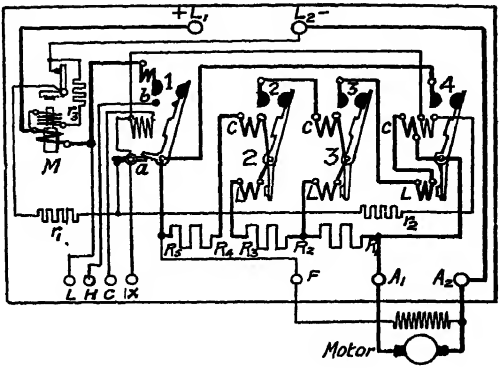


FIG 24.—Connections of Igranic automatic starter with two-coil series lock-out contactors (For description see p 23)

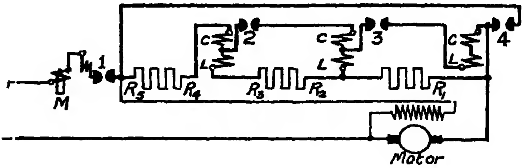


FIG. 25.—Schematic representation of main-circuit connections for Fig. 24

The starter shown in Fig 24 consists of four contactors. No. 1 has a shunt operating coil and is closed by a push-button or other control switch connected between terminals *L*, *C*. Nos. 2, 3, 4 each have two series operating coils, *C* representing the closing, and *L* the lock-out coil (see *Industrial Motor Control*, p. 69, for description of contactors).

When No 1 closes it establishes the motor circuit which includes the coils of contactor No. 2 and the three sections of the starting rheostat

When No. 2 closes, the resistance section R_2-R_3 is cut out by being shunted with the coils of No. 3, the resistance of which is very low in comparison with that of R_2-R_3.

Similarly, when No. 3 closes, resistance section R_1-R_2 is cut out Finally, section R_4-R_5 is cut out when No. 4 closes. Contactors Nos 2 and 3 then open automatically.

The overload relay is provided with both series and shunt coils. The shunt coil is permanently excited, but is insufficient to lift the plunger, although it will retain the plunger in the raised position when the latter has been lifted by the action of the series coil. When the plunger is lifted due to an overload the shunt operating circuit of contactors Nos. 1 and 4 is opened. This circuit cannot be re-established until the relay has been reset by hand.

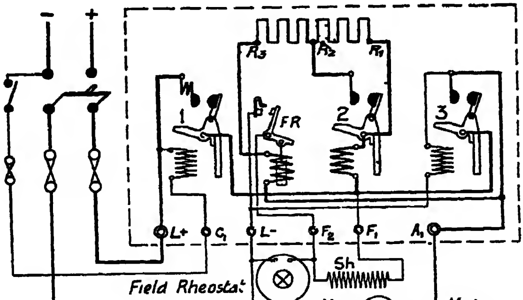


FIG 26 —Connections of Westinghouse automatic starter for adjustable speed motor

The starter consists of three contactors and a field relay (*FR*) Contactor 1 is excited by closing the control switch Contactor 2 is of the series lock-out type, contactor 3 is of the counter E M F type and closes when the voltage across the armature exceeds a pre determined value The field relay short circuits the field rheostat during starting

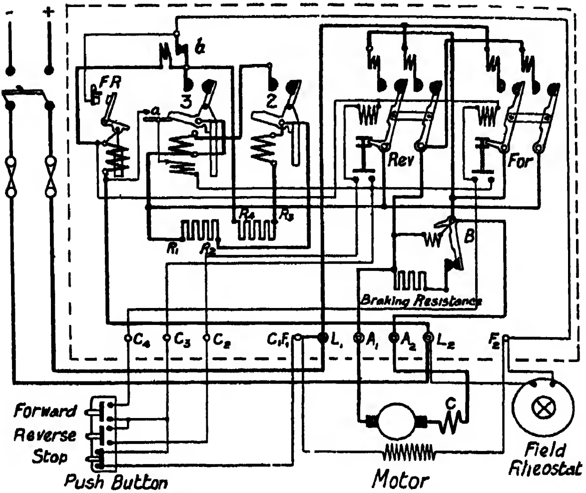


FIG 27.—Connections of B T -H (Type GE) automatic starter for reversible, long-range, adjustable-speed motor.

The starter consists of .—two D P contactors—one for each direction of rotation—two series lock-out contactors (Nos 2 and 3), a field relay, *FR*, and a contactor, *B*, for dynamic braking, this contactor being mechanically interlocked with the D P contactors so that it can only close when both of the latter are open In order to obtain maximum starting torque, the last accelerating contactor (No 3) is fitted with auxiliary contacts, *b*, which open when the contactor closes and remove the short-circuit from the field rheostat If the latter should be " all in," the action of the field relay, *FR*, will limit the armature current to a safe value while the armature accelerates to maximum speed The relay temporarily short-circuits the rheostat whenever the armature current exceeds a predetermined value, the contacts of the relay vibrating until the speed reaches that corresponding to the setting of the field rheostat

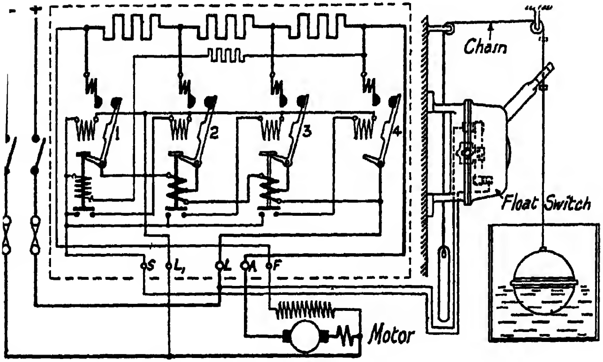


FIG 28.—Connections of B T.-H (Type RMC) automatic starter for controlling motor-driven pump operating on open tank system.

The starter consists of four contactors,[1] two of which are provided with series relays and one with a shunt relay, the latter being energized by the voltage drop across the starting resistances The plunger of each relay is held open mechanically until the contactor closes, when the plunger is free to drop as soon as the current input to motor falls to a predetermined value The release of a relay plunger completes the circuit to the operating coil of the next contactor

The first contactor (No 1) is closed by the float switch and the remaining contactors close automatically It should be observed that the opening of the float switch interrupts the operating-coil circuit of all the contactors

An illustration of this type of starter is given on p 183

[1] The contactors are described and illustrated in *Industrial Motor Control*, pp 75, 76

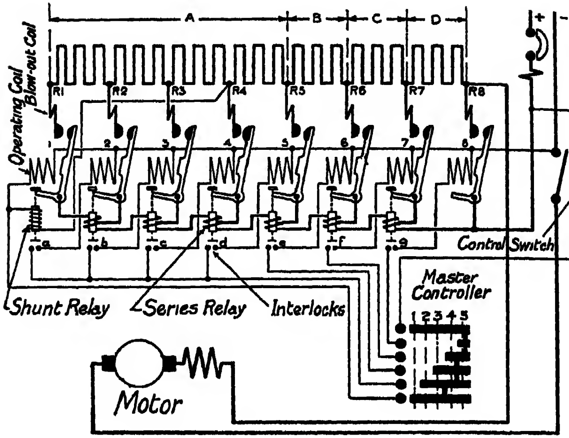


Fig 29.—Connections of B T -H (Type RMC) automatic starter with master controller arranged to provide for the starting and speed regulation of a series motor

The contactors are of the series-relay type The operating coil of contactor No 1 is excited on the first notch of the master controller, and the (shunt) relay of this contactor is energized by the voltage drop across a portion of the starting rheostat. When this voltage drop decreases to a predetermined value, the relay closes interlocks *a* and completes the circuit, up to the master controller, of the operating coil of the next contactor (No 2) which will close when the controller is moved to the second notch. Contactors 3, 4, 5 are energized by interlocks *b*, *c*, *d*, respectively, with the controller on the second notch, and the remaining contactors 6, 7, 8 will be energized with the controller on notches 3, 4, 5 respectively

After one resistance contactor closes, the next contactor cannot close until the motor current falls to a predetermined value Thus, in whatever manner the master controller is handled, the current input to motor is automatically limited.

Hand-operated controllers for series motors operating electric cranes, hoists, etc., may be divided into the following classes—

(1) Reversing controllers for starting and speed regulation by series resistance The fingers and segments are usually arranged so that limit switches can be used with the controller when desired. (Figs 30 and 38)

(2) Reversing controllers similar to class (1) but provided with extra finger and segments for use with shunt-wound brake magnets (Fig. 32)

(3) Reversing controllers arranged for slow starting by connecting resistance in parallel with motor armature. (Fig 34) Usually, only two or three slow-motion notches are provided for each direction These controllers are used principally for foundry cranes, and enable slow hoisting and lowering to be obtained irrespective of the load being handled

(4) Reversing controllers arranged for hoisting, dynamic brake lowering and power lowering (Fig 36.) With these controllers the power lowering notches are only intended for use when handling light loads A shunt-wound brake magnet must be used with this class of controller.

(5) Reversing controllers with power and dynamic braking notches for each direction of motion (Figs 42, 43) This class of controller is chiefly used on high-speed cranes, for the cross-traverse, longitudinal travel, or slewing motions, where it is desirable to check the speed more gradually than is possible by the application of a solenoid-operated mechanical brake The controllers are usually provided with two braking notches, a free-running position, and from three to five power notches on both sides of the "off" position

Limit switches, for preventing over-running, may be divided into two classes—(1) main-current limit switches, which are connected in the motor circuit; (2) auxiliary limit switches (B T-H system) which operate by short-circuiting the no-volt release coil of the circuit breaker on the control panel of the crane Examples showing the application of both types are given in Figs. 40, 41, 46.

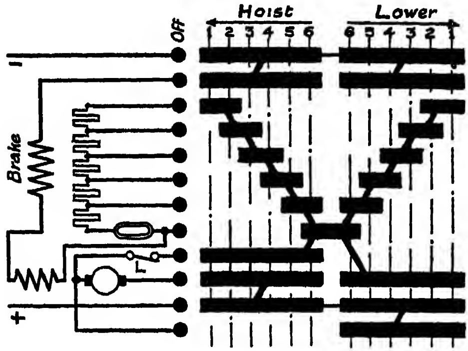


FIG 30 —Connections and development of reversing controller, for hoisting motor, with limit switch and series-wound brake magnet.

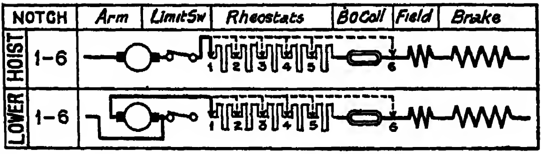


FIG. 31.—Combinations for Fig. 30 Note that the limit switch is cut out when lowering

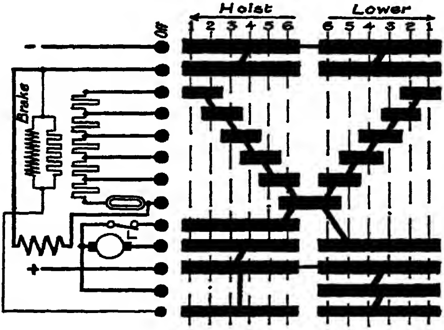


FIG. 32—Connections and development of reversing controller, for hoisting motor, with limit switch, shunt wound brake magnet and discharge resistance.

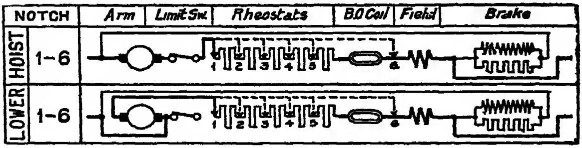


FIG 33—Combinations for Fig 32

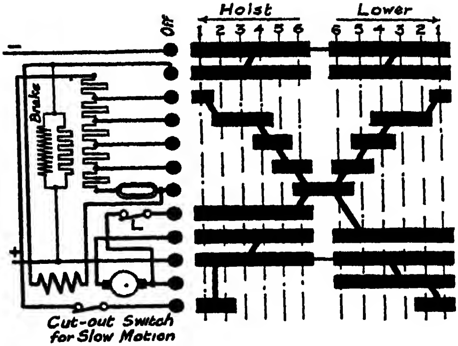


Fig 34 —Connections and development of reversing controller, for hoisting motor, arranged for slow motion hoisting and lowering The slow motion is obtained by connecting a portion of the rheostats in parallel with the armature of the motor, as shown in the diagram of combinations below

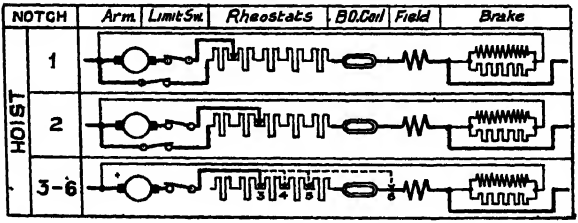


Fig. 35 —Combinations (hoisting notches) for Fig 34

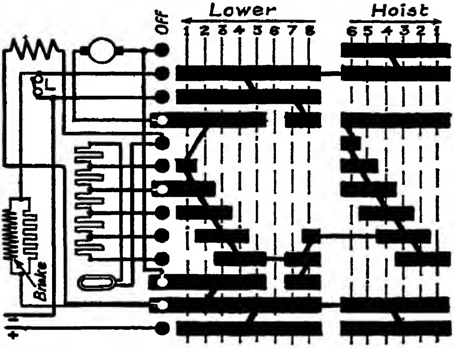


FIG 36.—Connections and development of [Metro-Vickers (Type HD)] reversing controller, for hoisting motor, arranged for dynamic lowering brake.

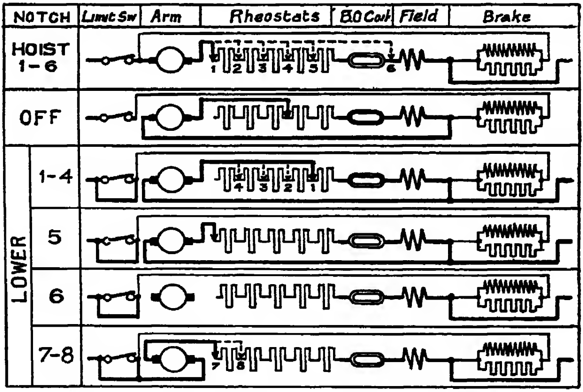


FIG 37 —Combinations for Fig 36 Lowering notches 1–5 are arranged for dynamic braking, notch 6 is arranged for free lowering, and notches 7, 8 are arranged for power lowering.

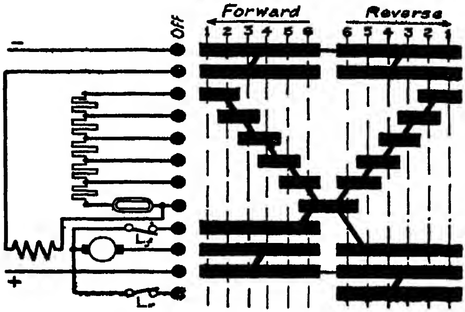


FIG 38.—Connections and development of reversing controller, for series motor, arranged with limit switches for longitudinal travel

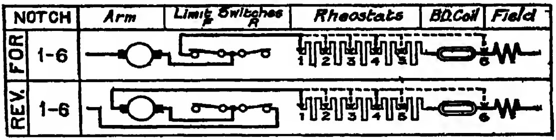


FIG 39 —Combinations for Fig 38.

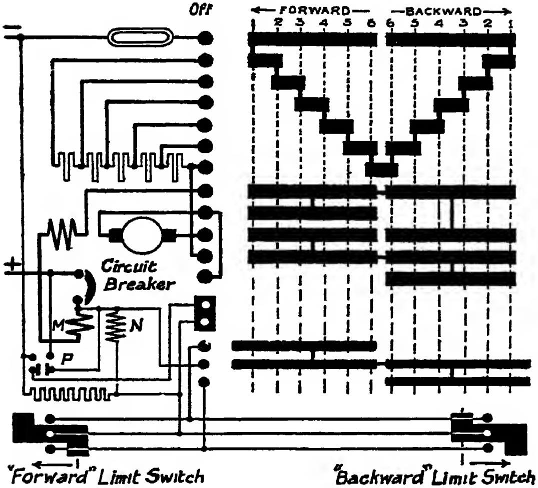


FIG 40 —Connections and development of [B T -H (Type R 506)] reversing controller, for series motor, with B T -H auxiliary limit switches (arranged for limiting the cross-traverse motions) and interlocking system.

The limit switches operate by short-circuiting the no-volt coil, N, of the circuit breaker To reclose the circuit breaker, the controller must be returned to the "off" position and the interlocking push-switch, P, pressed The operation of either limit switch only affects one direction of travel, so that it is always possible, when the circuit has been opened by exceeding the limit in one direction of travel, to return at full speed in the opposite direction

The switches are of the automatic reclosing drum type

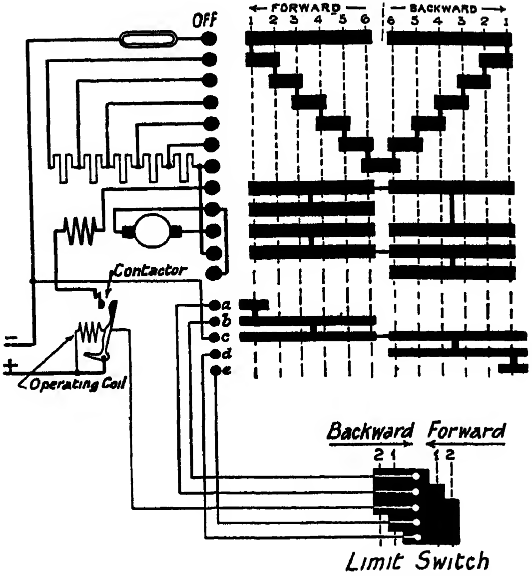


FIG. 41—Connections and development of [B T-H (Type R 506)] reversing controller, for series motor, with B T-H auxiliary limit switch for combined speed and travel limit

This limit switch is intended for the longitudinal travel motions and has two operating positions on either side of the central position

In the first position it is possible to operate the crane at a slow speed in one direction and full speed in the opposite direction, while, in the second position, the crane can only be operated in one direction Thus when the crane is near the end of its travel and the limit switch operates, it is possible to move a further distance in the same direction at a slow speed and to return at full speed

The switch is of the automatic reclosing drum type

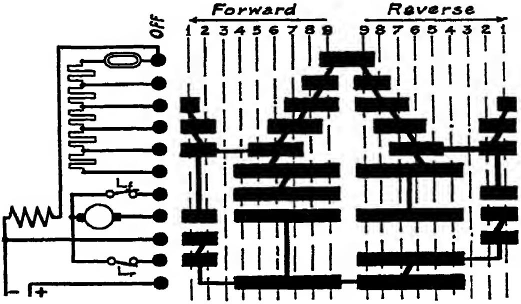


FIG 42—Connections and development of [General Electric (Type CB)] reversing controller, for series motor, arranged for dynamic braking in each direction of motion.

The combinations are similar to those given in Fig 44 except that, for the above controller, there are five power notches (instead of three), five sections to the rheostats and no brake magnet

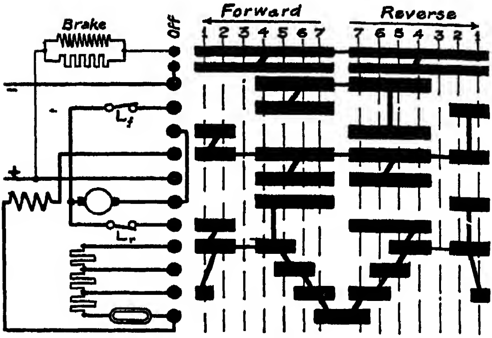


FIG. 43.—Connections and development of [Metro-Vickers (Type HE)] controller, for series motor, arranged for dynamic braking in each direction of motion and with shunt-wound brake magnet

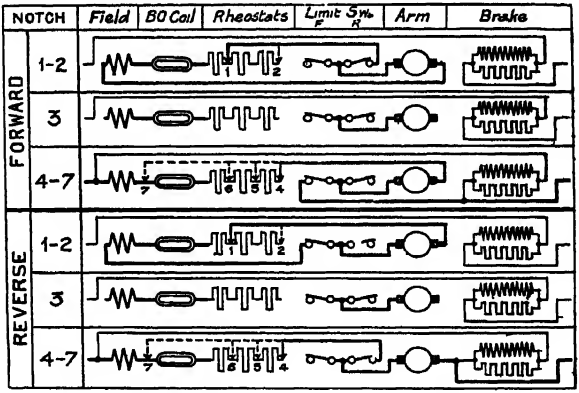


FIG. 44.—Combinations for Fig 43

Wiring diagrams for overhead travelling cranes.—In Figs. 45, 46 are given wiring diagrams for four-motor and three-motor overhead travelling cranes.

Fig 42 refers to a four-motor crane with main and auxiliary hoists and series-wound brake magnets for the hoisting drums The controllers are of the simple reversing type, without limit switch control, the connections and development being similar to Figs 30 and 38 except that the fingers, in these diagrams, to which the limit switches are connected are actually connected together at the finger board. The controller for the main hoisting motor is usually provided with from 7 to 9 notches in order to give gradual starting when handling heavy goods.

The switch panel in the cab is equipped with: main D.P. switch, D P. main fuses, S P. fuses for each motor, pilot lamps and inspection lamp plug receptacle In order to control the hoisting and traversing motors (which are mounted on the truck) from the cab, the armature and field circuits of these motors must be supplied through trolley wires suspended from the cross girders of the crane. With single-pole controller wiring[1] a common trolley wire may be used for connecting the negative main to all the motors on the truck so that the number of trolley wires required will be—

Two wires for the armature of each motor,
One wire for the field of each motor,
One wire for the common return to negative main

With double-pole wiring, as shown in Figs. 30, 32, 34, 38, 43, four trolley wires will be required for each motor on the truck.

If N = number of motors on the truck, T = number of trolley wires, then, for equipments without limit switches, we have—
(single-pole wiring) $T = 3N + 1$, (double-pole wiring $T = 4N$

When shunt-wound brake magnets are used in conjunction with the controller of Fig 32 an additional trolley wire will be required for each brake magnet on the truck

When main-current limit switches are used, one additional trolley wire will be required for each hoisting motor Thus for a three-motor crane with shunt-wound brake magnet and limit switch we shall require $[(3 \times 2) + 1 + 1 + 1 =]$ 9 wires with S P wiring and $[4 \times 2 + 1 + 1 =]$ 10 wires with D P. wiring

Fig. 46 illustrates the application of the B T-H. system of auxiliary current limit switches Two switches are required for the cross traverse and one for the longitudinal travel, the former being fitted to the crane girders and the latter to the cab The switches are of the type shown on p 33

The switch panel is fitted with a D.P circuit breaker (with overload and no-volt trip coils) and the motor circuits are protected by overload relays of the dashpot-time-limit type (B T-H system) The auxiliary contacts of the relays are connected to the no-volt coil of circuit breaker so that a sustained overload on any motor will trip the circuit breaker

The controller for the hoisting motor is arranged for slow starting—in accordance with Fig 34

[1] Controllers are wired "single-pole" when one terminal of motor is connected direct to negative main *See* Figs 36, 42

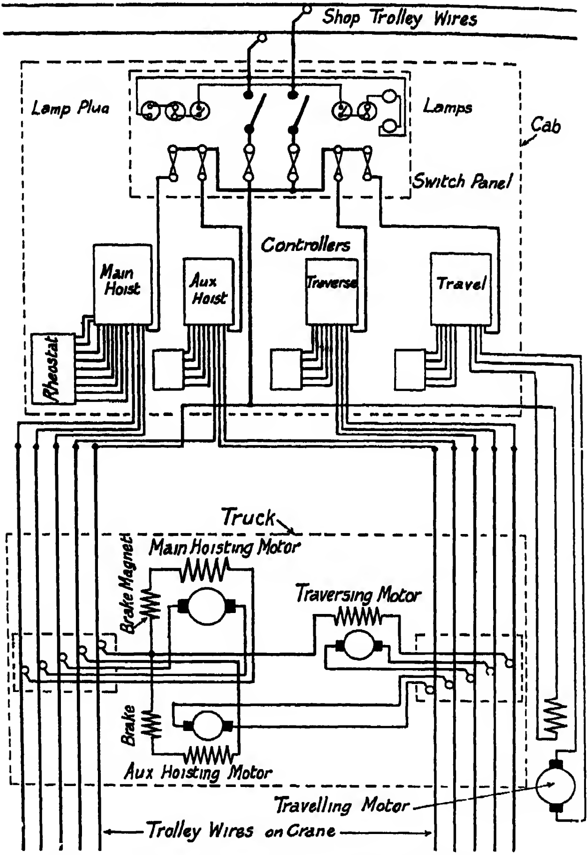


FIG 45 —Wiring for four-motor crane with main and auxiliary hoists and series brake magnets (Single-pole controller wiring)

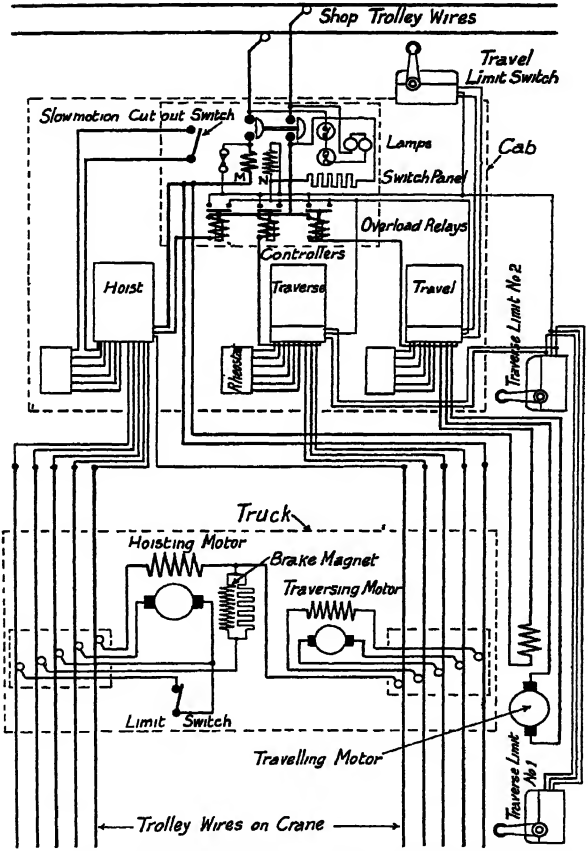


FIG 46 —Wiring for three-motor crane with shunt brake magnet and limit switches (Double-pole controller wiring for hoisting motor)

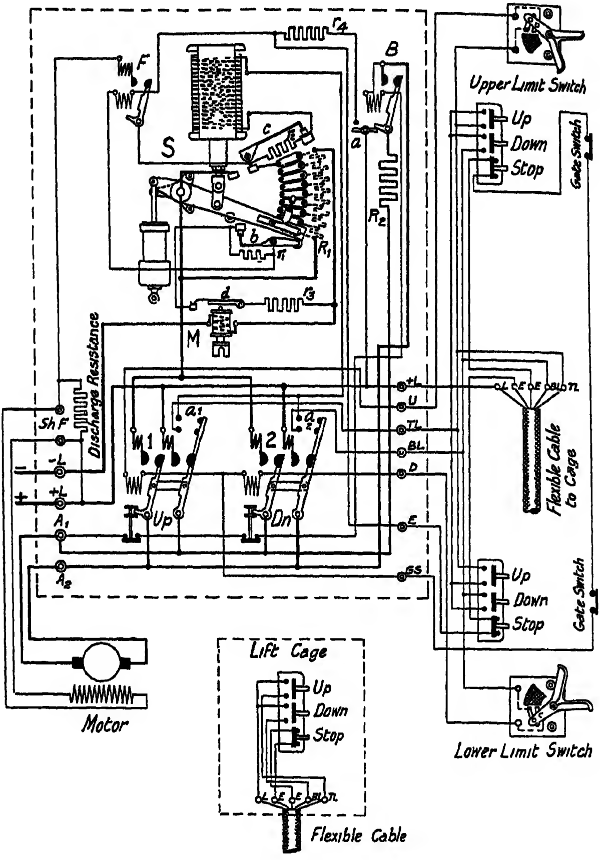


Fig 47 —Connections of Igranic automatic controller for 2-floor push-button lift (For factory or warehouse)

The **lift controller**, Fig. 47, consists of an automatic switch panel and the following accessories—two limit switches, two gate switches, two sets of push buttons, each set consisting of three buttons—"up," "down," "stop." The automatic switch panel is equipped with—An automatic, solenoid operated, starting rheostat, S; two D P. contactors, Nos 1 and 2, for reversing the motor; an overload relay, M; a contactor, B, for dynamic braking and a contactor, F, for exciting the motor field.

Assuming the cage to be at the lower limit of its travel (the lower limit switch being open) and the gates closed, pressing any of the "up" buttons will complete the control circuit of contactors F and No. 1, which will close provided that the switch lever of starting rheostat is in its first position. When contactor No 1 closes, the auxiliary switch a_1 establishes two circuits, viz, (1) the retaining circuit for contactors F and 1 and (2) the operating circuit for the automatic starter S.

The paths of the various circuits are as follows · *Operating circuit for contactors* 1 *and* F :—L (+)—"up" button—upper limit switch—terminal U—coil No. 1 contactor—terminal GS—gate switches—"stop" buttons—terminal E—coil, contactor F—interlock switch b, short-circuiting interlocking resistance, r_1—auxiliary contacts, d, of overload relay M—resistance r_2—L (—) *via* M.

Retaining circuit for contactors 1 *and* F :—L (+)—auxiliary switch a_1—terminal TL—upper limit switch—terminal U—etc., (as above) to L (—).

Operating circuit for automatic starter :—L (+)—auxiliary switch a_1—solenoid—switch c, for short-circuiting resistance r_2—L (—) *via* M.

The retaining circuit remains closed until the lift reaches the top of its travel when the upper limit switch opens.

For the "down" journey the operation is similar, except that a "down" button is pressed, contactor No 2 is closed, and the lower limit switch is included in the control circuit

The "stop" buttons are all connected in series, and the lift may be stopped at any point of its travel by pressing one of these buttons

When stopping, contactors F and 1, or 2, open and contactor B automatically closes, reclosing contactor F by means of auxiliary switch a The dynamic braking resistance, R_2, is thus connected across the motor armature with the field fully excited, so that a quick stop is obtained Contactors B and F open automatically when the voltage across the motor armature falls to a low value

In the case of a passenger lift, a floor switch would be fitted in the car, which renders the push buttons outside the car inoperative while a passenger is in the car

A control panel for a 4-floor lift is illustrated in Fig 226, p 183, and illustrations of limit switches are given in Figs. 227, 228, 229

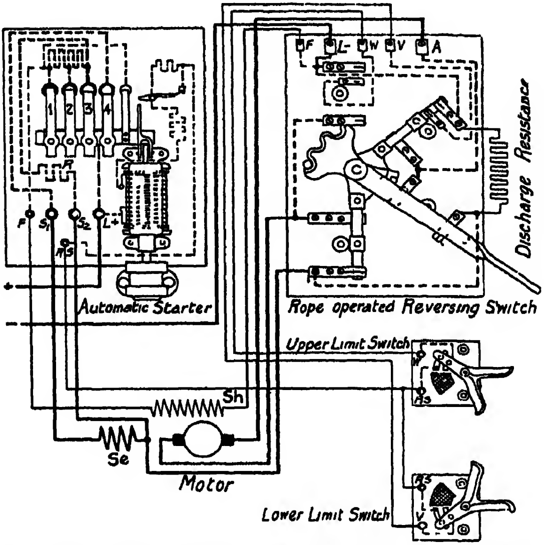


FIG 48—Connections of Igranic controller for service lift rope-operated control switch

The control gear consists of an automatic starting rheostat and a rope-operated, quick make and break, D P. reversing and control switch—with "up," "down," and "off" positions

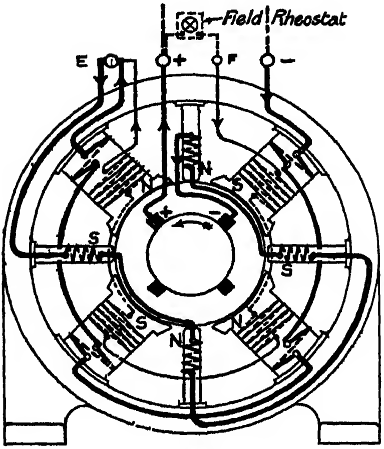
The automatic starter is of the multiple-finger type. When the reversing switch is thrown to either of the "on" positions, the control circuit of the starter is completed and resistance is cut out from the motor circuit, the series field being finally shunted by the resistance *R* The control circuit is opened automatically, by the operation of the appropriate limit switch, just before the lift reaches the limit of its travel, the motor circuit being opened at the starter The lift can only be restarted (in the reverse direction) by operating the reversing switch The lift, however, may be stopped at any point of its travel by moving the reversing switch to the "off" position, and it may then be restarted in either direction

SECTION 2

Direct-current Generators and Balancers

Internal connections of two- and three-wire compound-wound, commutating-pole generators—Internal and external connections of compound-wound, commutating-pole, balancer—Connections of starting rheostats for balancers—Connections of non-reversing and reversing potentiometer-connected field rheostats.

A



B

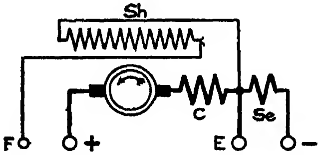


FIG. 49 —Internal connections of compound wound, commutating-pole generator with retrogressive armature winding Rotation counter-clockwise

Diagram *A* shows the magnetic polarities of the main poles necessary to obtain a given (electrical) polarity at the brushes The polarities of the commutating poles for the conditions given are also shown

Diagram *B* shows schematically the circuit relations of the various windings

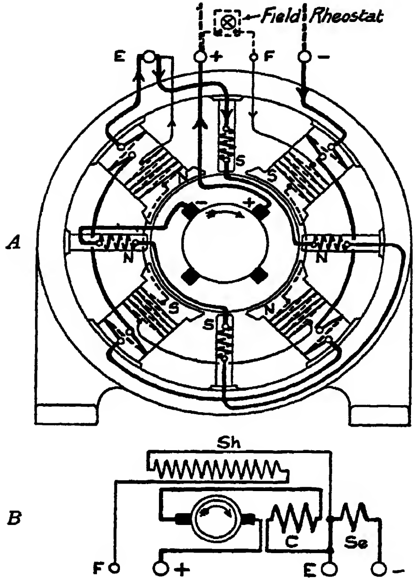
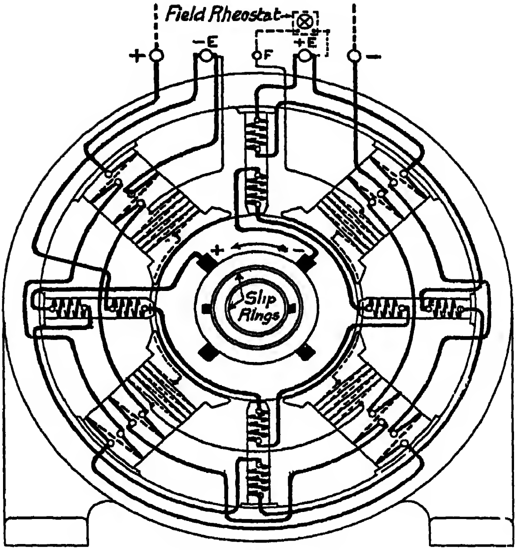


FIG 50 —Internal connections of compound wound, commutating-pole generator with retrogressive armature winding. Rotation clockwise

Diagram *A* shows the magnetic polarities of the main poles necessary to obtain a given (electrical) polarity at the brushes The polarities of the commutating poles for the conditions given are also shown

Diagram *B* shows schematically the circuit relations of the various windings If this diagram be compared with Fig 49, it will be seen that for reversal of rotation, the connections between the armature and commutating-pole windings must be reversed.

A



B

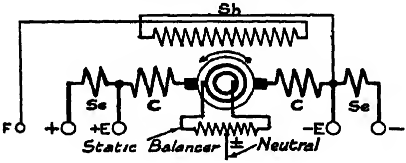


FIG. 51.—Connections of compound wound, commutating-pole generator for three-wire supply A reference to the schematic diagram *B* will show that the series and commutating-pole windings are divided, one-half of each winding being connected on each side of the armature The commutation and compounding, therefore, are not affected by unbalanced loads

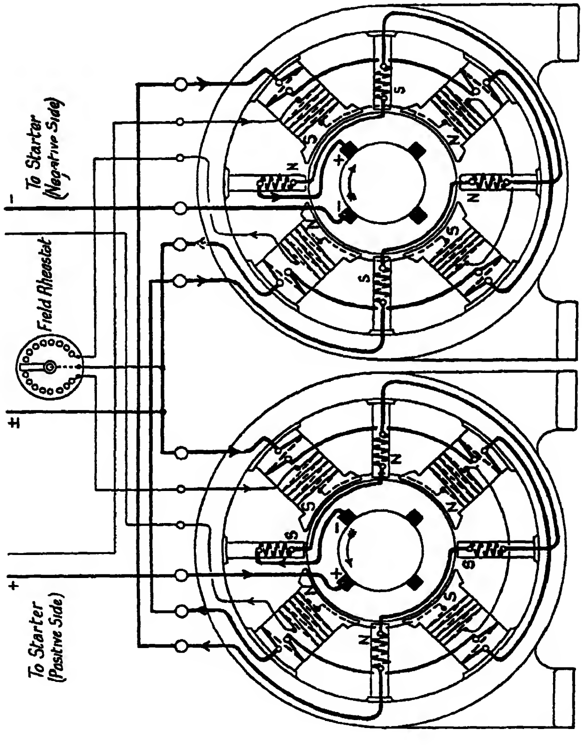


FIG 52 —Connections of compound wound, commutating-pole balancer set The arrows indicate the directions of the currents in the various windings when both machines are motoring

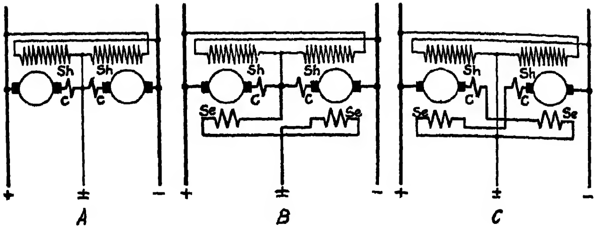


Fig. 53—Methods of connecting shunt- and compound-wound balancers.

Balancers must be used when a three-wire system is supplied from a single two-wire generator, or from a group of generators operating in parallel, in order that equal voltages may be maintained on each side of the system under conditions of unbalanced load.

A balancer consists of two similar machines, coupled together, each machine being either shunt or compound wound. With shunt machines, the shunt windings are cross-connected, as indicated in diagram *A* Thus when a difference of voltage exists between the two sides of the system, due to unequal loads, the machine on the lightly-loaded side has its field weakened, and operates as a motor, while the machine on the heavily-loaded side has its field strengthened, and operates as a generator

The balancer therefore, tends to equalize the voltages on the two sides of the system

In order to improve the voltage regulation it is necessary to use compound-wound machines The shunt windings are cross-connected, as above, and the series windings are either both connected in series with the neutral wire—as shown in diagram *B*—or cross-connected as shown in diagram *C* In each case the series winding is arranged so that it assists the shunt winding when the machine is generating, and opposes the shunt winding when the machine is motoring

[For a full discussion on the theory of balancers see a series of articles on "Balancers for three-wire continuous-current systems," by Mr Thomas Carter, in *The Electrician*, vol 78, p 466 *et seq*.]

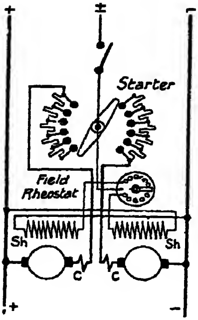


FIG 54

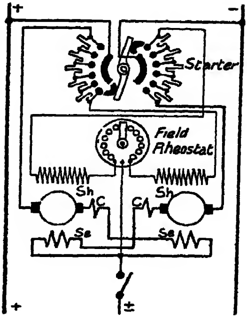


FIG. 55

Alternative connections of starting gear for balancers.

A balancer set must be started by operating both machines as motors. A special type of starting rheostat —having a double set of contacts and resistances, with a single switch lever—is used The starter may take two forms—one, Fig. 54, being suitable for connection to the neutral wire and known as a "mid-wire starter"; the other, Fig 55, being arranged for connecting between each armature and the corresponding "outer," and known as a "double-pole starter" The starters are not usually fitted with automatic releases, owing to the unbalanced voltages which might result if the balancer were wrongly disconnected from the system.

Field rheostats for use with balancers are usually arranged so that when resistance is cut out from the field circuit of one machine an equal resistance is inserted in the field circuit of the other machine The rheostats are specially connected and are provided with three terminals, two being connected to the two ends of the resistance and one to the contact lever

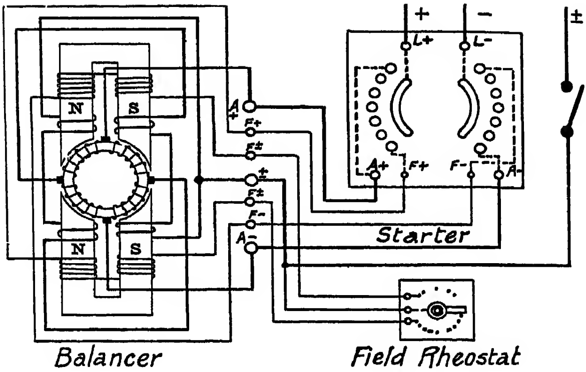
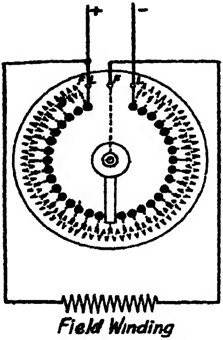


FIG 56—Connections of Crompton (Type C M.B) balancer with D P starter and field rheostat

The balancer is a modification of the C M B. auto-converter [1] The machine has a single armature, with a ring winding, and a special magnetic circuit

[1] See *The Electrician*, vol 63, pp 498, 506, for a description of this machine



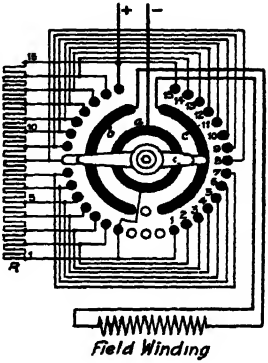


FIG 57. FIG. 58.

Connections of non-reversing and reversing potentiometer-connected field rheostats.

Potentiometer-connected rheostats are used principally in connection with boosters, split-pole rotary converters and generators which have to operate over a wide range of voltage.

In the reversing rheostat, Fig. 58, the resistance *R* consists of 14 sections which are connected to two sets of contacts, one end (No. 15) of the resistance being connected to the positive line The negative line is connected to contact ring *a* and the field winding is connected to the contact segments *b*, *c* The switch lever has two sets of brushes which are insulated from each other One brush connects the resistance contacts with either of the field segments *b*, *c*, and the other brush connects either of these segments with the negative main

When the switch lever occupies the vertical position the field winding is un-excited.

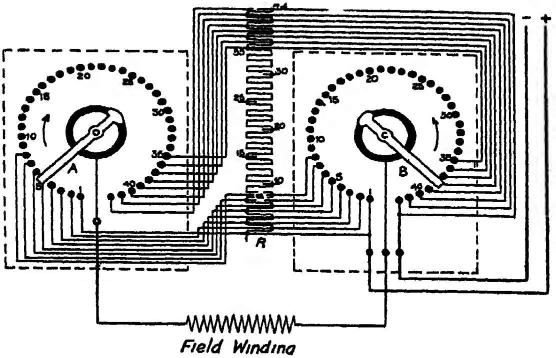


FIG 59 —Connections of B.T -H. reversing potentiometer-connected field rheostat.

The rheostat consists of two switch dials *A*, *B*, the contact levers of which are mechanically connected together (but insulated from each other), and a resistance *R* divided into a suitable number of sections Each end of the field winding is connected to one of the contact levers and the resistance sections are connected to the contacts so that the two levers move electrically in opposite directions Thus, one end of the resistance is connected to the positive line and the other to the negative line, and when lever *A* is making contact with the positive end, the lever *B* will be at the negative end and *vice versa* When each lever occupies the central position—i e both are connected to the same point of the resistance *R*—the field winding will be short-circuited

SECTION 3

Direct-current Switch Panels

Connections of switch panels for shunt- and compound-wound two- and three-wire generators with rotary and static balancers—Garage (battery charging) panels—Combined battery and generator panels for isolated plants—Battery-charging booster panel—Mercury-Arc and "Tungar" Rectifier equipments for battery charging—Automatic reversible booster panels (Entz and Lancashire)—Panels for reducer sets

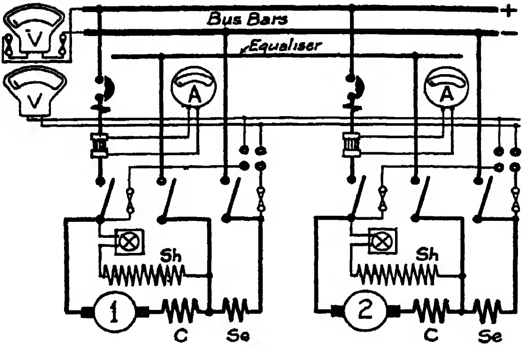


FIG. 60.—Connections of switch panels for compound-wound commutating-pole generators.

The equipment of each panel includes—circuit breaker, three S P switches, ammeter, field rheostat, 4-point potential plug receptacle for "machine" voltmeter.

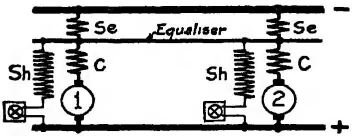


FIG. 61.—Schematic diagram for Fig. 60 showing machine circuits.

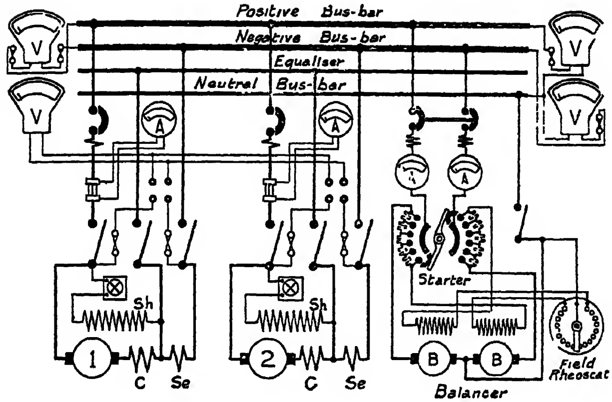


FIG 62—Connections of switch-panels for compound-wound commutating-pole generators supplying three-wire system on which rotary balancers are used.

The generator panels are similar to those of Fig 60 The balancer panel is equipped with a D P interlocked circuit breaker, two ammeters, a S P switch for neutral wire, a D P starter and a field rheostat.

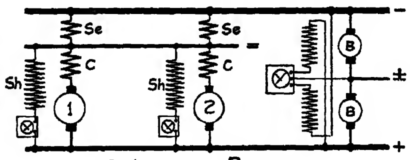


FIG 63—Schematic diagram for Fig 62 showing machine circuits.

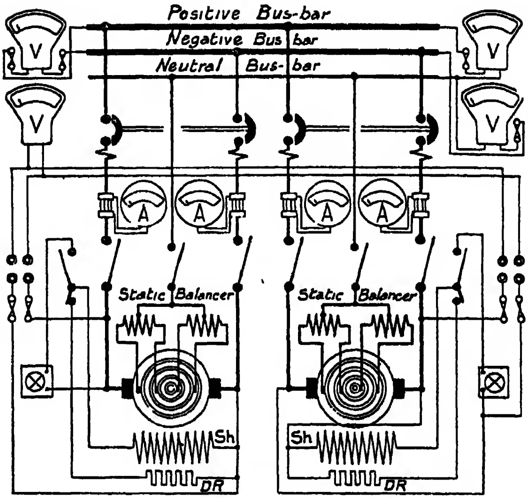


FIG 64 —Connections of switch-panels for shunt-wound generators supplying three-wire system on which static balancers are used. [Note.—The slip rings on generators are arranged for two-phase static balancers *See* Fig 121, p 103, for connections of balancers.]

Each panel is equipped with —a D P circuit breaker, with tripping coil on each pole, two ammeters; three S P switches (positive, negative and neutral); a 4-point potential plug receptacle, a field discharge switch and a field rheostat,

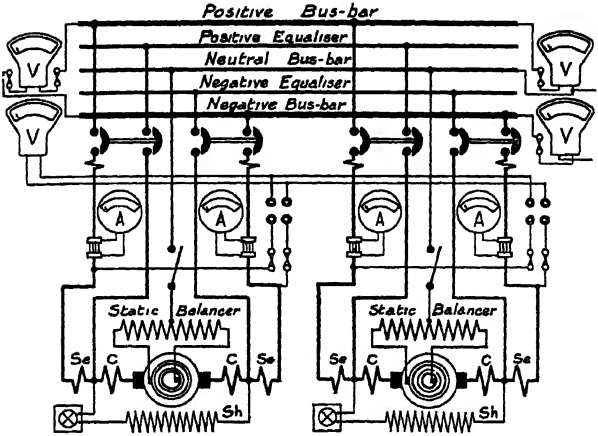


FIG 65 —Connections of switch-panels for compound-wound commutating-pole generators supplying three-wire system on which static balancers are used

Each generator must have the series and commutating-pole windings divided and connected in accordance with Fig. 51 (p. 46) With this type of generator it is necessary to use D.P. circuit breakers on each side of the system in order that the circuits of a main and equalizer of like polarity may be opened and closed simultaneously. The circuit breakers must be mechanically interlocked so that an overload on *either* side of the system will open *both* (positive and negative) circuit breakers.

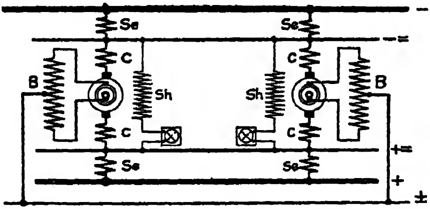


FIG 66 —Schematic diagram for Fig. 65 showing machine and static-balancer circuits

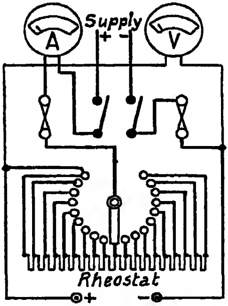


FIG. 67 —Connections of garage switch panel for charging small accumulators from a D C supply system

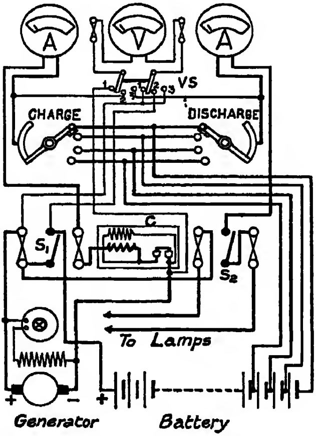


FIG 68 —Connections of switch panel for isolated generator and battery plant Single circuit load, Neville automatic cut-in and cut-out switch (*c*).

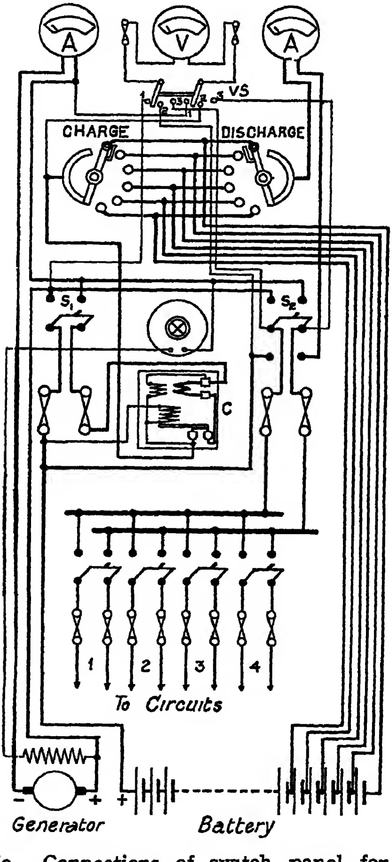


FIG 69.—Connections of switch panel for isolated generator and battery plant Multiple circuit load: Crawley automatic cut-in and cut-out switch (*c*)

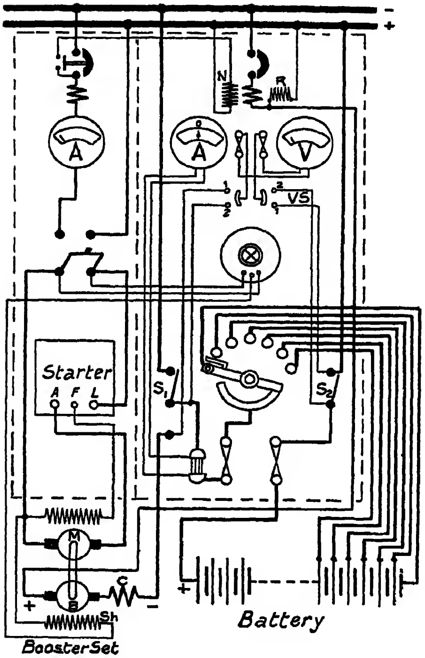


FIG 70.—Connections of battery and booster panels

The battery is charged from the bus-bars through the booster by throwing switch S_1 to lower contact, and closing switch S_2 and the circuit breaker. The circuit breaker on the battery panel is electrically interlocked with that on the motor panel so that the opening of the motor circuit breaker will trip the booster circuit breaker

Voltmeter switch positions—

(1) (Bus-bar + booster) volts

(2) Battery volts.

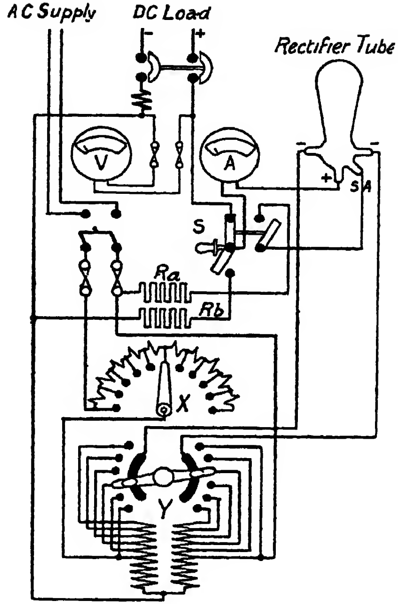


FIG 71 —Connections of switch panel for mercury-arc rectifier

The panel is arranged for battery charging, variation of the D C voltage being obtained by means of the regulating and compensating reactances *X*, *Y* The starting and load switches, *S*, are shown in the " load " position. At starting the switches are thrown to the lower and auxiliary contacts, thereby connecting the starting anode *SA* to one terminal of the A C supply *via* resistance *Ra* and the main anode (+) to the centre point of the compensator or auto-transformer *Y via* resistance *Rb* The arc is started by tilting the tube, and after the arc is established the switch *S* is thrown (up) to the load position

[*See* p 68 for connections of " Tungar " rectifier.]

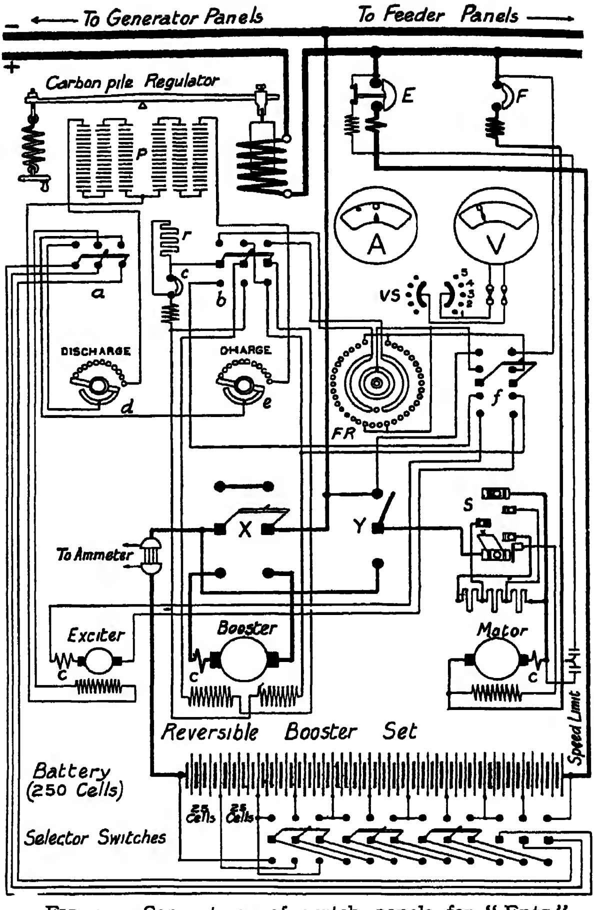


FIG. 72.—Connections of switch panels for "Entz" automatic reversible battery-booster [Chloride Electrical Storage Co]

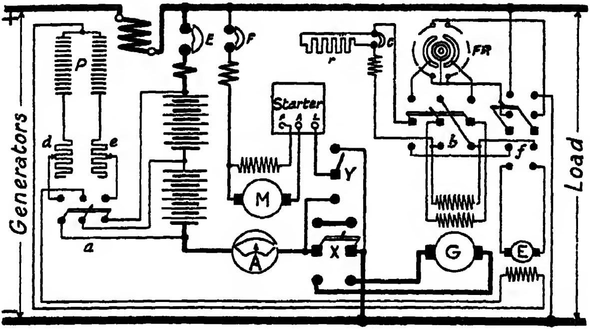


FIG. 73 —Schematic diagram for Fig. 72.

The booster set consists of three machines—motor, booster and exciter The booster is shunt wound and is excited from the exciter, the field of the latter being controlled by means of a carbon-pile regulator This regulator (*see* Fig. 253, p. 200) consists of two sets of piles of carbon discs, between which is pivoted a lever. From one end of the latter is suspended an iron core surrounded by a solenoid carrying the entire generator load · to the other end of the lever is attached a spiral spring, the tension of which is regulated to counterbalance the pull of the solenoid. The exciter field winding is connected between the mid points of piles and battery as shown in Fig 73

When the generator load is such that the pull of solenoid is equal to the tension of the spring, both sets of piles will be subjected to equal pressure and the exciter will be unexcited.

Variations in the total load above or below this fixed *generator* load will cause changes in the pressure on the piles and will affect their contact resistance, thus exciting the exciter in one direction or the other according to which set of piles is compressed. The booster will, therefore, charge or discharge the battery to maintain a constant load on the generators.

References for Figs 72 and 73 —*X*, booster switch (" up," battery floating on bus-bars; " down," automatic working), *Y*, motor main switch (" up," motor across bus-bars, " down," motor across battery), *S*, motor starting switch, *FR*, reversing potentiometer-connected field rheostat (used when booster is excited from bus-bars for fully charging battery); *a*, exciter control switch, *b*, T P, D.T switch for booster fields (" up," fields in series—for non-automatic working—" down," fields in parallel—for automatic working), *c*, exciter circuit breaker with substitutional resistances, *r*, *d*, *e*, equalizing rheostats (for varying sensitiveness of regulation); *f*, D P, D T switch for booster field excitation (" up," bus-bar excitation, " down," exciter excitation).

Voltmeter switch positions —(1) Battery (2) bus-bars, (3) exciter, (4) booster, (5) battery + booster

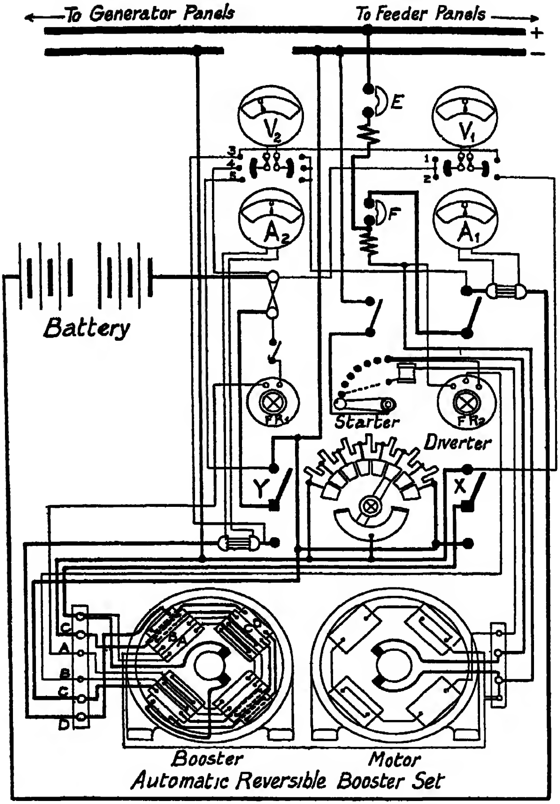


FIG 74.—Connections of switch panels for "Lancashire" automatic reversible battery-booster. (Lancashire Dynamo and Motor Co.)

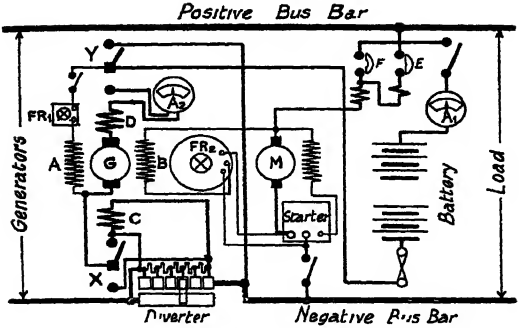


FIG 75 —Schematic diagram for Fig 74

The booster set consists of two machines—motor and booster. The booster is built with a laminated magnetic circuit and has four field windings—two shunt windings *A*, *B*, and two series windings *C*, *D*. The shunt winding *A* is excited by the difference of voltage between bus-bars and battery, while the winding *B* is separately excited from the bus-bars, the excitation being adjusted by means of a potentiometer-connected field rheostat, FR_2. The series winding *C* is excited by current proportional to the generator load, while the winding *D* is for the purpose of compensating armature reaction and voltage drop in the booster.

Automatic regulation is secured by arranging: (1) that the booster voltage resulting from excitation due to winding *A* shall equal the difference between bus-bars and battery voltages; (2) that the charge and discharge of battery are controlled by windings *B* and *C*, the former supplying a definite excitation—with a given bus-bar voltage—in the *same* direction as that due to winding *A*, and the latter supplying an *opposite* excitation proportional to the load current. Thus the battery will be charged when the load current is below a given value—depending on the adjustment of diverter and FR_2—and will be discharged when the load exceeds this value, thereby maintaining a constant load on the generators

At periods of light load the battery and booster may be connected to bus-bars without the generators and the combination will give either a level- or an over-compound characteristic according to the adjustment of the diverter In this case winding *A* must be disconnected by means of switch *Z*, and winding *B* must be reversed [1]

[1] When this method of operation is required, the field rheostat FR_2 must be of the *reversing* potentiometer type (*see* Fig 58, p 51).

The switch gear is arranged to provide for the following combinations—(1) Battery and booster on bus-bars with generators (switches *X*, *Y*, "down", *Z*, closed) · (2) Battery on bus-bars without booster and with or without generators (switches *X*, *Z*, open, *Y*, "up"): (3) Battery and booster on bus-bars without generators (*X*, "up", *Y*, "down"; *Z*, open).

Voltmeter switch positions—(1) Booster, (2) bus-bars and booster—battery [for paralleling purposes], (3) bus-bars and booster, (4) battery, (5) bus-bars

REDUCERS[1] for supplying searchlight and kinema arcs from D C circuits of moderate voltage (200 to 500 volts), are more efficient than motor-generators since only a portion of the energy required by the arc is supplied by the generator of the reducer set, the remaining portion being taken direct from the supply circuit.

A constant voltage may be supplied to the arc circuit by means of shunt machines connected according to Fig 76 In this case it will be necessary to insert a series (or "steadying") resistance in the arc circuit in order to obtain a stable arc

With differentially compounded machines, connected in accordance with Fig 77, no series resistance is required as the volt-ampere characteristics of the set are such that the conditions for a stable arc (i e. a decrease in voltage with an increase in current, and *vice versa*) are fulfilled This result is obtained by providing the generator with a differential compound winding and the motor with a cumulative compound winding, *each* series winding carrying the current taken by the arc

With the Crompton (Type C M B) auto-converter the two machines of Fig. 77 are combined, and similar volt-ampere characteristics are obtained The auto-converter, however, must have a ring armature winding and a special magnetic circuit, as indicated in Fig 78[2]

[1] A reducer (sometimes called a dynamotor) consists of two machines—or, alternatively, two separate armature windings on a common core, with a common magnetic circuit—the armatures of which are connected in series across the supply circuit, the load circuit being supplied from one of the armatures The machine is, therefore, analogous to an alternating-current auto transformer

[2] See *The Electrician*, vol 63, pp. 498, 506, for a description of this machine

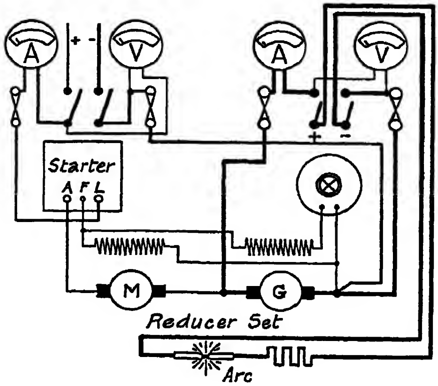


FIG. 76.—Connections of shunt-wound reducer for supplying searchlight or kinema arcs.

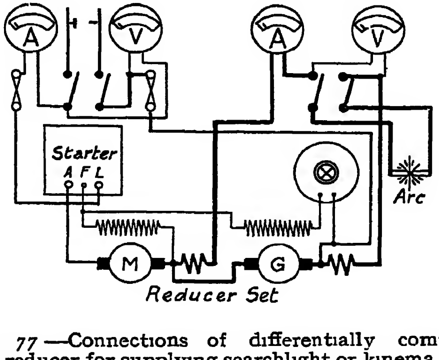


FIG 77—Connections of differentially compound-wound reducer for supplying searchlight or kinema arcs.

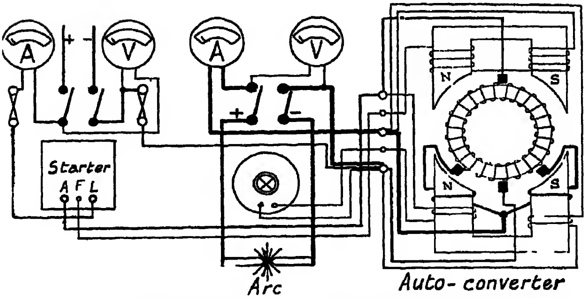


FIG 78—Connections of Crompton (Type C.M.B.) auto-converter for supplying searchlight or kinema arcs.

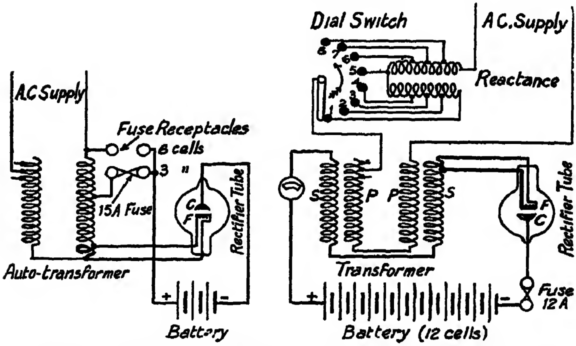


FIG 79—Connections of B T.-H "Tungar" thermionic rectifiers for battery charging.

The diagram on the left gives the connections of a small rectifier (suitable for charging batteries of 3 or 6 cells at currents up to 6 amp), that on the right gives the connections of a larger rectifier (suitable for charging batteries of from 3 to 12 cells at currents up to 5 amp) In the small rectifier two fixed charging voltages (7 5 V and 15 V) are available by inserting the fuse in the appropriate receptacle In the larger rectifier eight charging voltages (from 5 V to 30 V) are available, the adjustment being effected by a dial switch and a tapped reactance connected in the primary circuit.

SECTION 4

Control Apparatus for Alternating-current Motors

Hand-operated and automatic starters for single-phase motors—Hand-operated starters and controllers for polyphase motors (including motors with pole-changing windings)—Automatic starters for polyphase motors—Controllers for alternating-current cranes—Wiring for overhead travelling crane.

Hand-operated and Automatic Control Apparatus for Single-phase Motors.—Self-starting (commutator) **Motors**—which are of either the series or repulsion types—are started by connecting a resistance in series with the motor The starting rheostats are, therefore, similar to those for continuous-current series motors, certain modifications being necessary due to the use of alternating currents These modifications relate to the no-volt and overload releases, and, in the case of self-acting starters, to the magnetic circuit of the operating solenoid. For examples *see* Figs 80, 81, and 231 (p 185)

To reverse direction of rotation interchange leads connected to *excitation* winding

Single-phase Induction Motors are incapable of starting against heavy loads The stator winding may take two forms (1) a single-phase winding with an auxiliary (or starting) winding spaced 90° from it ; (2) a standard three-phase winding With each type it is necessary, at starting, to supply one of the windings with current differing in phase from that in the other winding (or windings) in order that a rotating field may be set up

A mo or with a single-phase (main) winding and an auxiliary (starting) winding is started by supplying the former through a resistance and the latter through a reactance (e g a choking coil) The resistance inserted in the main winding limits the current taken by this winding and results in an increased phase-difference between the currents in the two windings When the motor has accelerated sufficiently, the starting winding and resistance are cut out, thus leaving the main winding connected directly across the mains With motors having wound rotors, the rotor resistances are cut out *before* changing the stator connections

To reverse direction of rotation interchange leads connected to either stator winding

Examples of starters for this type of motor are shown in Figs 83, 84, 230 (p 184)

In the case of a motor having a three-phase stator winding all the phases are used at starting, and by means of resistance and reactance the currents in the several phases are made to differ in phase When the motor has run up to speed the resistance and reactance are cut out, and two phases (in series) are supplied directly from the mains, the change-over being effected by means of a double-throw switch (*See* Fig 82 for example)

To reverse direction of rotation interchange any pair of stator leads

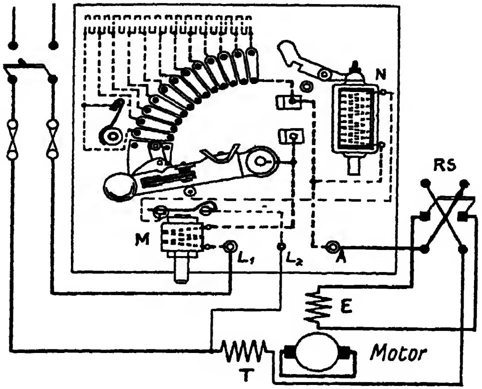


FIG 80.—Connections of starting rheostat and reversing switch for reversible repulsion motor [Electrical Apparatus Co]

The motor is reversed by reversing the connections of the excitation winding E

The overload release, M, operates by open-circuiting the no-volt coil, N

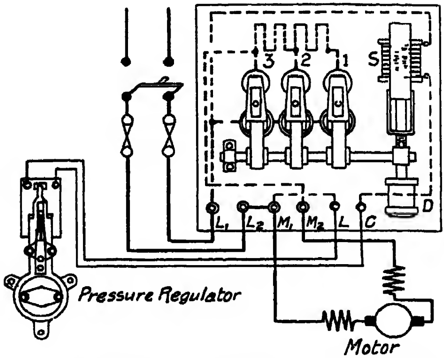


FIG. 81—Connections of Igranic multiple-finger type, self-acting starter with pressure regulator for compensated series motor

This starter operates on the same principle as the D C starter shown in Fig 16 *See* Figs. 231 (p. 185), 218 (p. 177), for illustrations of starter and pressure regulator.

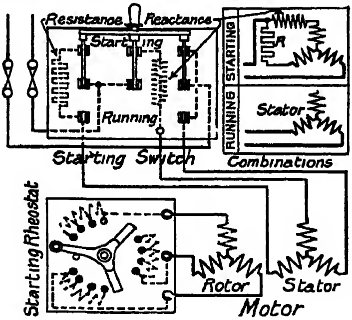


FIG. 82.—Connections of starting switch for single-phase induction motor with three-phase stator winding

At starting, resistance and reactance are inserted in two of the phases of stator The rotor rheostat is then gradually cut out and the starting switch is thrown to "running" position.

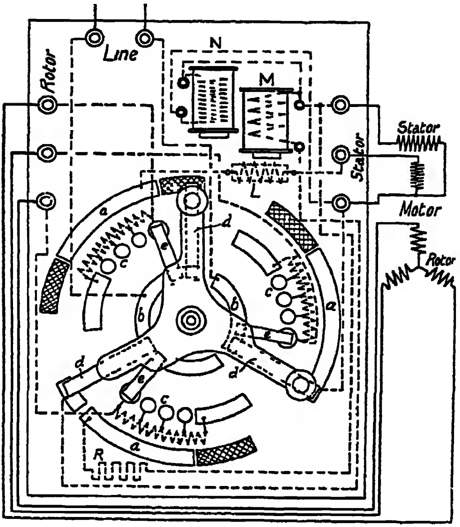


FIG 83 —Connections of combined starting switch and rheostat for single-phase induction motor. [Ellison]

At starting, a resistance *R* is inserted in series with the main stator winding and a reactance *L* is inserted in series with the auxiliary winding. These are cut out after the rotor resistances have been short-circuited, thus leaving only the main winding in circuit

The starting switch consists of—three " stator " segments, *a* , two " line " segments, *b* , three sets of rotor resistance contacts, *c* , insulated brushes, *d*, connecting *a* and *b* , uninsulated brushes, *e*, connecting phases of rotor resistances

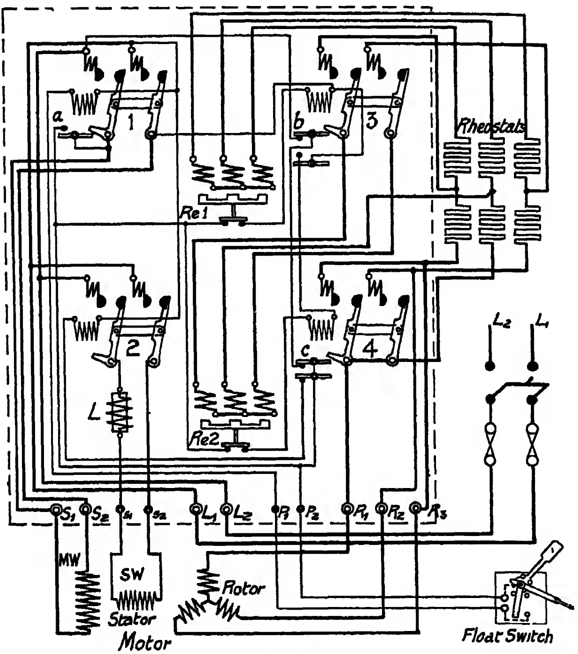


FIG 84—Connections of Igranic automatic starter for single-phase induction motor operating motor-driven pump working on open tank system.

The stator of motor is wound with main and starting windings (*MW SW*) A reactance, *L*, is connected in series with the latter at starting

The operating coils of contactors Nos 1 and 2 are energized by the closing of the float switch, provided that Nos 3 and 4 are open When No. 1 closes, the interlocking circuit through auxiliary switches *b* and *c* is cut out, and the operating circuit for Nos 3 and 4 (*via* contacts of relays *Re* 1, *Re* 2) is established by means of auxiliary switch *a*.

The current limiting relays *Re* 1, *Re* 2 are operated by the rotor current When *Re* 1 closes, contactor No 3 is energized, and auxiliary switch *b* completes the circuit of coil No 4 up to the contacts of relay *Re* 2 When No 4 closes, the circuit of No. 2 is opened automatically by auxiliary switch *c*

The opening of the float switch opens the operating circuit of No 1 contactor, which, on opening, interrupts the operating circuit of Nos 3 and 4.

Hand operated control apparatus for polyphase motors may be classified as follows: (1) Starting switches for single-speed motors[1] with squirrel-cage rotors; (2) starting rheostats and controllers for single-speed motors with wound rotors; (3) starting switches and controllers for multi-speed motors with squirrel-cage rotors; (4) controllers for multi-speed motors with wound rotors.

Small motors (up to about 1½ h.p.) may be started by switching directly on to the supply circuit; but larger motors, with squirrel-cage rotors, must be started with reduced voltage—obtained by means of an auto-transformer. The equivalent of a reduction in the voltage impressed on motor is obtained by re-grouping the windings at starting. Thus, for a three-phase motor, if the windings are delta connected for "running" and star connected for starting, the voltage impressed on each phase at starting will be only 57.7 per cent of the normal. This method, however, is limited to motors up to about 25 h.p.[2]

Larger motors must be started by means of auto-transformers, which are provided with several tappings in order that a voltage may be selected to suit the conditions under which the motor has to start.[3] Examples of starters for motors with squirrel-cage rotors are given in Figs. 85, 96 and 232 (p. 185), 233 (p. 186).

With **motors having wound rotors** the starting is effected by means of resistances connected in the rotor circuit. Rotor windings are usually three-phase, star connected; but with certain small motors a two-phase winding, *L*-connected, is used. Examples of starting rheostats are given in Figs. 97-100 and 234 (p. 187). Examples of controllers are given in Figs. 101, 103, 235, 236.

Multi-speed motors, having squirrel-cage rotors, may be obtained with pole-changing windings to give two, three, or four synchronous speeds, the three- and four-speed motors requiring two distinct stator windings. With two- and four-speed motors the stator windings are arranged so that the number of poles (of each winding) may be changed in the ratio of 2 : 1. The change in the connections is effected by either a double-throw switch or a controller. Examples are given in Figs. 104, 106.

In the case of motors having wound rotors it is necessary to provide separate rotor windings and rheostats for each combination of the stator winding. Hence it is only practicable to adopt two speeds. An example of a controller of this type of motor is given in Fig. 107.

To reverse the direction of rotation of polyphase motors—*Two-phase motors*—interchange stator leads of *one* phase. *Three-phase motors*—interchange any pair of stator leads.

[1] i.e. motors having one synchronous speed.

[2] This method is only suitable for light load starting, the starting torque not exceeding one half of the full load torque.

[3] *See* page 173.

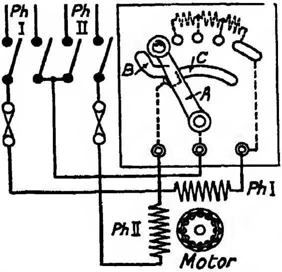


FIG 85.—Connections of starting rheostat for small two-phase motor.

The switch lever, *A*, in addition to its own contact brush, carries a second brush, *B*, which is insulated from it and makes contact with the segment *C*, the brushes being fixed a distance apart equal to the pitch of the contacts At starting equal resistances are inserted in each phase and are cut out in three steps by the movement of the lever

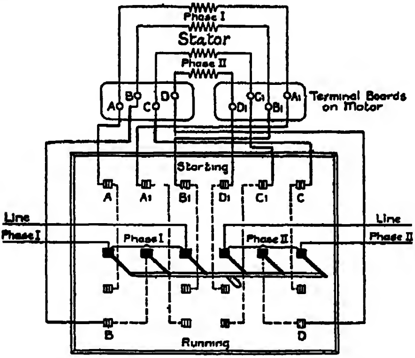


FIG 86.—Connections of B T-H series-parallel starting switch for two-phase motors with squirrel-cage rotors

Each phase of the motor is wound in two sections At starting these sections are connected in series for normal working they are connected in parallel, the combinations being effected by means of a six-bladed D T switch Thus the equivalent of half voltage is thrown on the motor at starting.

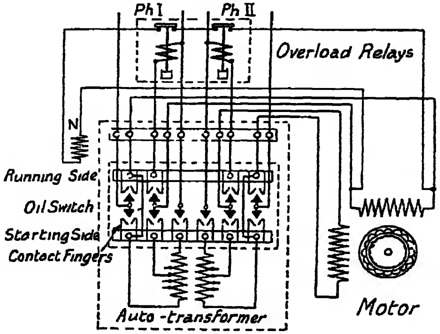


FIG 87—Connections of B T-H. (Type NR) auto-transformer (or Compensator) starter for two-phase motor with squirrel-cage rotor.

The starter consists of a two-phase auto-transformer and a double-throw oil switch, the latter being held in the "running" position by a catch provided with a no-volt release Overload protection takes the form of two time-limit overload relays, the auxiliary contacts of which are connected in series with the no-volt coil, N. The relays are only in circuit when the switch is in the "running" position

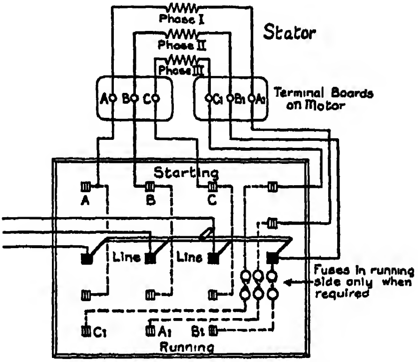
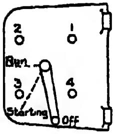


FIG. 88 —Connections of B T -H. star-delta starting switch for three-phase motors



End view of switch, showing positions of handle and fingers

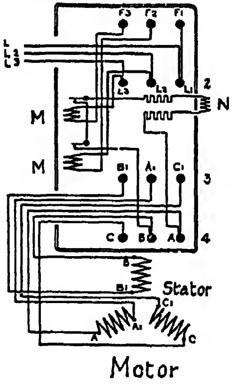


FIG. 89 (Connections)

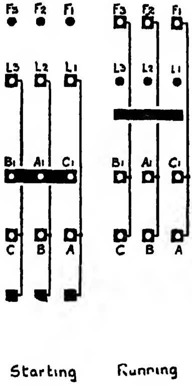


FIG 90 (Development)

FIGS 89, 90 —Connections and development of B T -H , drum type, star-delta starting switch with overload and no-volt releases (*M* and *N* respectively)

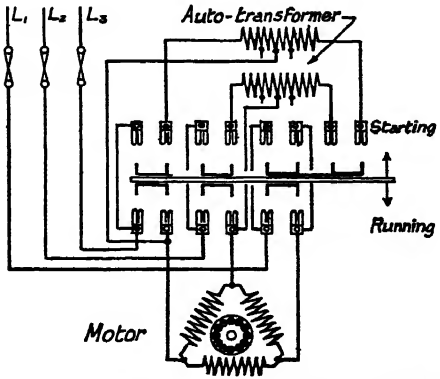


FIG. 91.—Connections of Metropolitan-Vickers auto-transformer starter for three-phase motors.

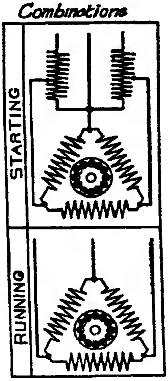


FIG 92 —Combinations for auto-transformer starters using " V "-connected auto-transformers (as in Figs 91, 93, 94).

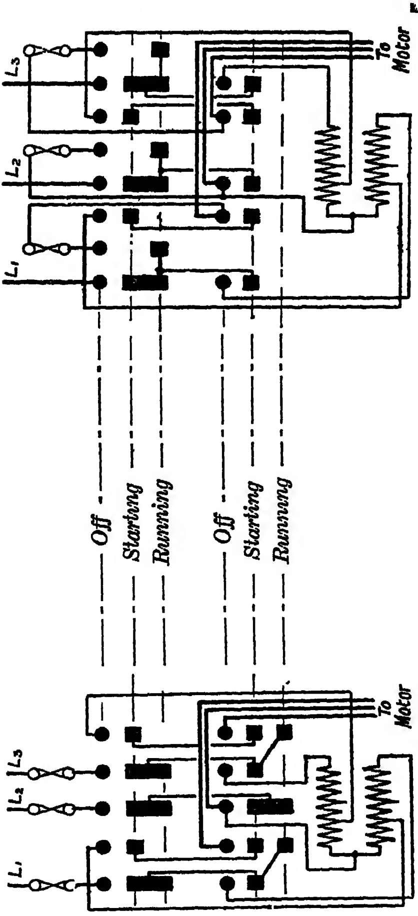


Fig. 94.

Fig 93.

Connections of General Electric (Witton), drum type, auto-transformer starters for three-phase motors. The starter of Fig. 94 is arranged so that the fuses are cut out during starting. Hence with this starter the motor is better protected under running conditions than with the starter of Fig 93. [*See* Fig 232, p 185, for view of starter.]

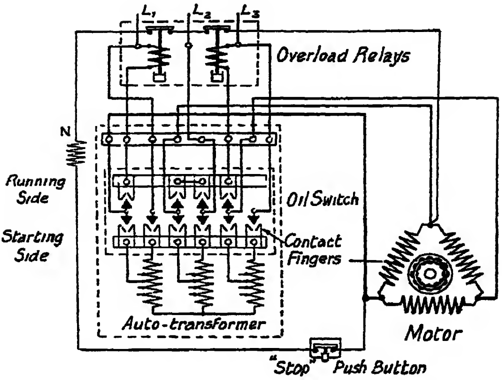


FIG 95 —Connections of B T -H (Type NR) auto-transformer starter for three-phase motor The starter consists of a three-phase auto-transformer and a double-throw oil switch, the latter being held in the "running" position by a catch provided with a no-volt release Overload protection takes the form of two time-limit overload relays, the auxiliary contacts of which are connected in series with the no-volt coil N In the circuit of this coil is also connected a "stop" push button, which may be used for stopping the motor On the release of the holding-in catch, the switch returns to the "off" position under the action of a spring

NOTE —A view of the oil-switch portion of a starter is given in Fig 2 3 (p 150)

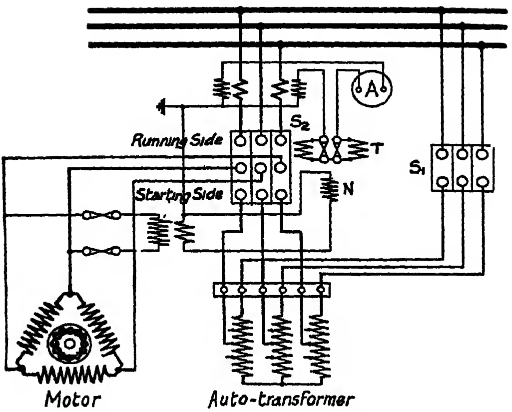


Fig 96.—Connections of B T -H. auto-transformer starting-gear for high voltage three-phase motor.

The starting-gear comprises—a three-phase auto-transformer; a T P, S T oil switch, S_1, a T P, D T oil switch, S_2, with no-volt release, N, and overload trip coils, T To start motor, switch S_1 is closed—which excites the auto-transformer—switch S_2 is thrown to the "starting' side and, after the motor has accelerated sufficiently, is thrown to the "running" side Switch S_1 is then opened.

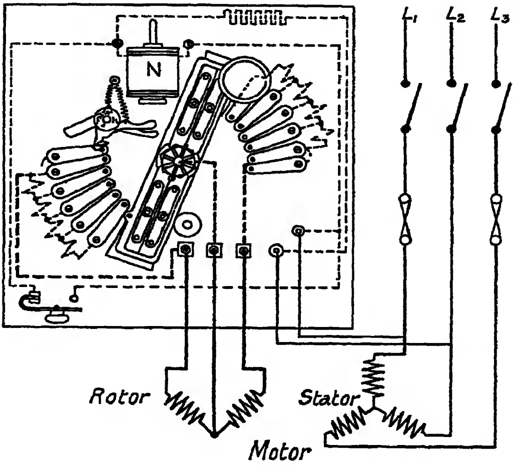


FIG. 97.—Connections of B T -H. starting rheostat for small three-phase motor with two-phase rotor winding. The starting rheostat is provided with a no-volt release coil, N, which is connected in series with a resistance across two of the stator phases The switch lever may be released by closing the auxiliary switch, which short-circuits the no-volt coil

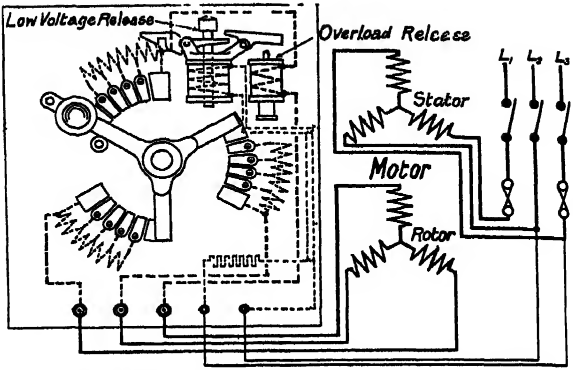


FIG 98.—Connections of Igranic starting rheostat for three-phase motor

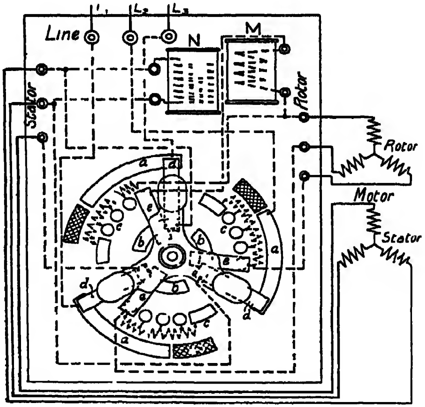


FIG 99 —Connections of combined starting switch and rheostat for three-phase motor [Ellison] For illustration, *see* Fig 234, p 187.

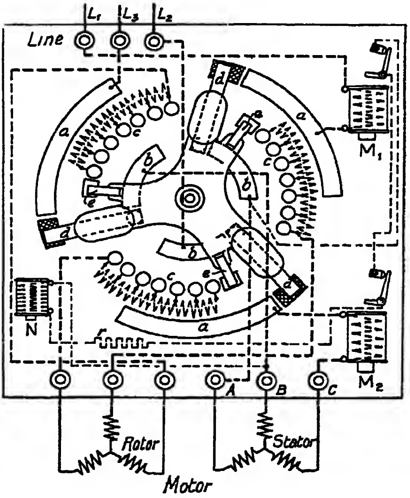


FIG 100—Connections of B T-H combined starting switch and rheostat for three-phase motor

Note to Figs. 99 and 100.—The starting switch consists of—three " line " segments, *a* , three " stator " segments, *b* , three sets of rotor resistance contacts, *c* , insulated brushes, *d*, connecting *a* and *b* , uninsulated brushes, *e*, connecting the phases of rotor resistances

The starter of Fig 99 is fitted with no volt and overload releases, the overload coil, *M*, being connected in the *rotor* circuit The two releases are mechanically interlocked with the holding-in catch of switch lever, so that the operation of either coil will release the lever

In the case of Fig 100, the switch lever is held in the " running " position by a catch controlled by the no-volt coil, N This starter is provided with two overload coils, M_1, M_2, which are connected in two phases of the stator, and the operation of either coil will open the circuit of the no-volt coil

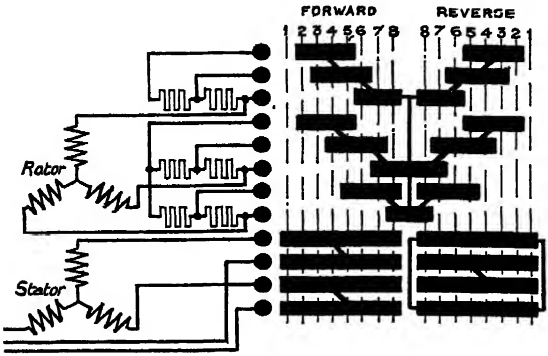


FIG 101.—Connections and development of reversing controller for three-phase motor.

Eight notches in each direction are obtained, with only two rheostat sections per phase, by arranging these sections to be cut out *successively* from each phase. An unbalancing of the phases will occur on some notches, but, for industrial purposes, an unbalancing up to 40 per cent in the relative values of the phase currents does not seriously affect the operation of the motor.

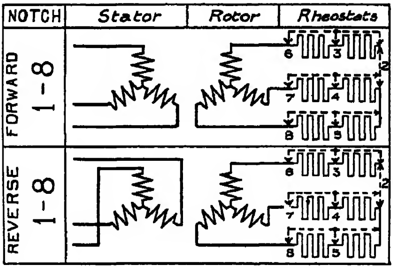


FIG. 102.—Combinations for Fig 101

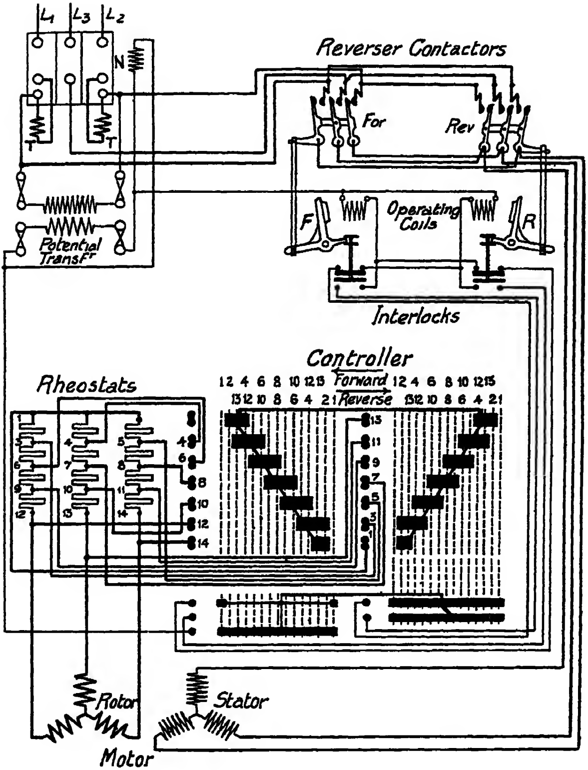


FIG 103 —Connections and development of B T -H. reversing controller for high-voltage three-phase motor.

The reversing is effected by two T P contactors (mechanically and electrically interlocked) which are electrically operated by means of auxiliary contacts on the controller, the operating-coil circuit being supplied from a potential transformer.

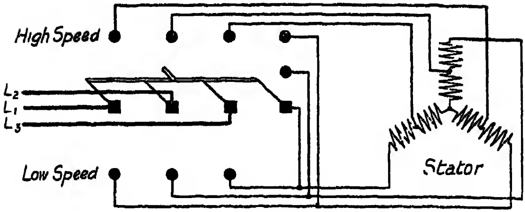


FIG. 104—Connections of pole-changing switch for two-speed three-phase motor with squirrel-cage rotor (NOTE.—The stator is wound with a single pole-changing winding, the numbers of poles corresponding to the combinations being in the ratio of 2 : 1.)

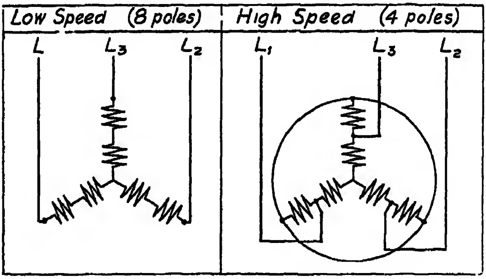


FIG. 105—Combinations for Fig. 104.

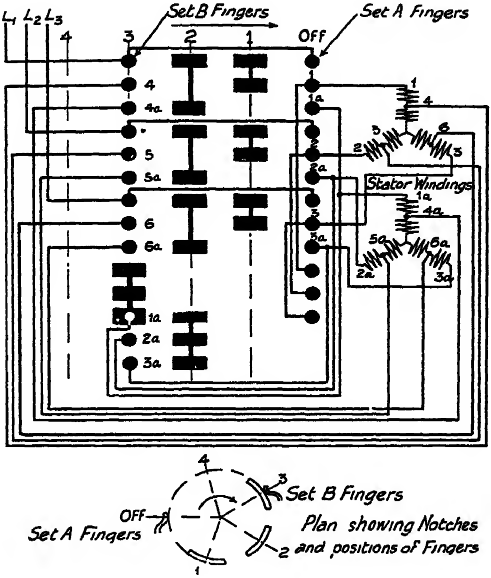


FIG 106 —Connections and development of B.T -H pole-changing controller for four-speed three-phase motor with squirrel-cage rotor

The stator is wound with two pole-changing windings, each being connected so that the number of poles may be changed in the ratio of 2 : 1 Thus, according to the number of poles selected for these windings, synchronous speeds in the ratio of 1 : 1·25 : 2 : 2·5 ; 1 : 1·33 : 2 : 2·66 ; 1 : 1·5 : 2 : 3 ; 1 : 1·66 : 2 : 3·33 ; 1 : 2 : 2·5 : 5 ; 1 : 2 : 3 : 6 ; 1 : 2 : 4 : 8, etc , may be obtained

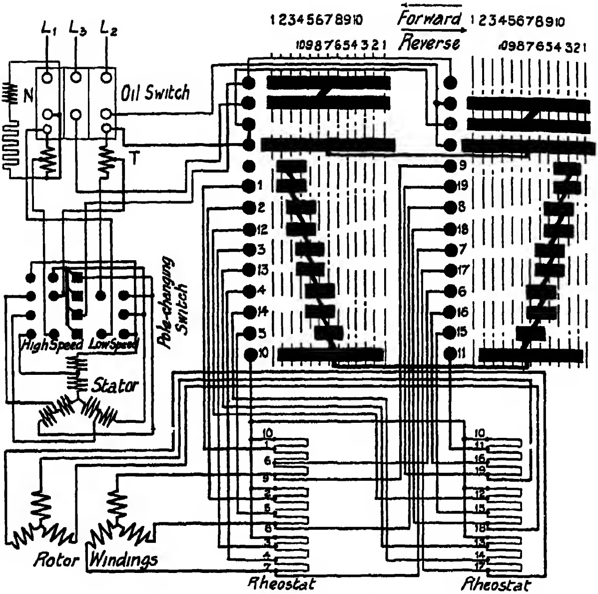


FIG 107—Connections and development of B T -H reversing controller for two-speed three-phase motor with wound rotor *See* Fig 108 for combinations

The stator is wound with a single pole-changing winding which is connected so that the number of poles may be changed in the ratio of 2 1, the pole-changing switch being mounted on the frame of the motor

The rotor is wound with two windings—corresponding to the pole numbers of the stator combinations—and each winding is provided with a separate set of slip-rings and rheostats

Since motors of this type are usually rated on a basis

of constant torque (i e. increased output at higher speeds) the line current corresponding to full load with high speed combination will be approximately double that corresponding to full load with the low-speed combination. Thus, to obtain complete overload protection it is necessary to use an oil switch with double-wound trip coils In the present case, the trip coils (T) are interconnected with the pole-changing switch so that, when operating with

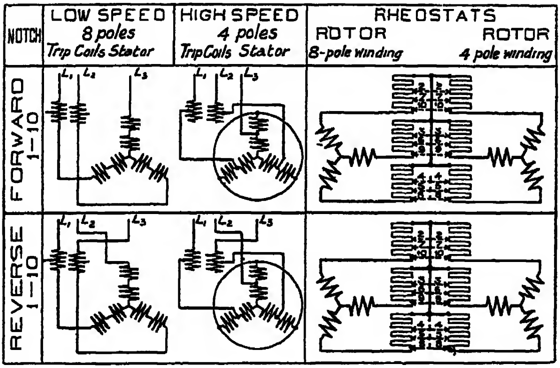


FIG 108 —Combinations for Fig 107

the low-speed combination, the full coil-winding is in circuit, but, when operating with the high-speed combination, one-half of the coil-winding is cut out

Each phase of the rheostats is divided into three sections and the sections are cut out successively from each phase, thus giving 10 controller points in each direction of rotation for both the high-speed and the low-speed combinations of stator winding

Automatic control systems for polyphase alternating-current motors involve the use of contactors and current limiting relays, by means of which the rate of closing of the accelerating contactors is controlled The control of the motor is effected by means of push buttons, a pilot switch, a float switch or a pressure regulator (or governor) With motors having wound rotors the current limiting relays may be connected either in stator or rotor circuit, but with motors having squirrel-cage rotors the relay must be connected in the stator circuit

Motors having squirrel-cage rotors are started with reduced voltage, which is obtained either by series resistance or from an auto-transformer Two contactors are necessary. one connects the motor to the starting rheostat (or auto-transformer) and the other, which is controlled by the current-limiting relay, connects the motor directly to the line Only one starting point is required because, with normal designs of motors, any voltage which will start the motor will accelerate it to nearly synchronous speed The method in which an auto-transformer is used is preferable to that in which a rheostat is used since, for equal starting torques, the line current will be lower. The voltage impressed on motor at starting should be such that the starting operation occupies from 4 to 8 seconds If the starting period is much less than 4 seconds a lower voltage can be used. while, if the period is greater than 8 seconds, a higher voltage is necessary [1]

Motors having wound rotors are started by inserting resistances in the rotor circuit, the sections being cut out by contactors controlled by current-limiting relays The number of sections depends on the size of motor and the nature of the load against which the motor has to start. The contactors and resistance sections are so arranged that all phases of the rotor are balanced during starting (*see* Figs. 111, 112)

Alternating-current contactors are shunt wound and are usually operated with single-phase current, a single magnet being used with double-, triple- or four-pole contactors (*see* Figs. 230, 237 for examples)

For high-voltage circuits two types of contactors are used—(*a*) the air-break type with magnetic blow-out and special arc chute, (*b*) the oil-immersed type, the former being suitable for heavy-duty service such as mine hoists, rolling mills, etc, while the latter is suitable for services requiring infrequent starting and stopping In each case the operating coils and control circuit are supplied at suitable voltage by means of a potential transformer, while the series coils of the relays (when these are connected in the stator circuit) are supplied from current transformers

[1] *See* page 173 for data relating to starting performance of motors with squirrel cage rotors

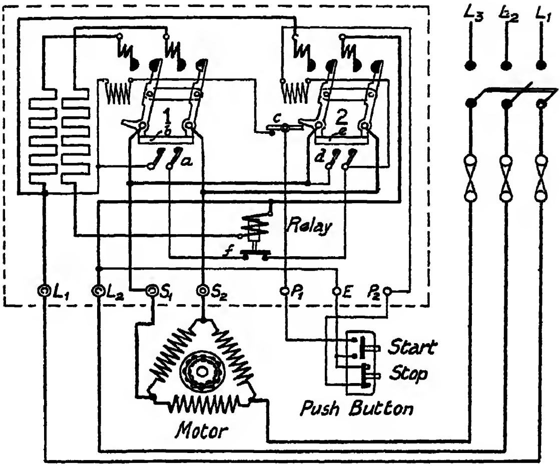
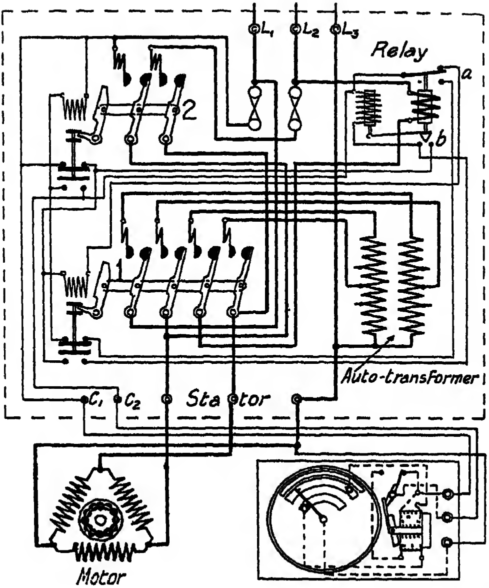


FIG 109 —Connections of Igranic automatic resistance starter, arranged for push-button control, for three-phase motor with squirrel-cage rotor [Igranic Electric Co]

Pressing the "start" button completes the control circuit of No 1 contactor, which, on closing, connects the motor to the supply mains, resistances being inserted in two of the phases The closing of contactor No 2 is controlled by the current-limiting relay and the interlocks *a*, the latter only being closed when No. 1 is closed When the plunger of relay drops, No 2 closes (thereby cutting out the starting resistance) and the circuit of No. 1 is opened by the auxiliary switch *c* At the same time a retaining circuit, *via* the "stop" button, is established by means of contacts *d*, *e*



Pressure Governor with Relay

FIG 110 —Connections of B T -H (Type CR) automatic auto-transformer starter and pressure governor for three-phase motor with squirrel-cage rotor [*See* Fig 216 for illustration of pressure governor and Fig. 233 for illustration of contactor panel]

Contactor No 1 is energized by the relay of pressure governor completing the circuit between terminals C_2 C_1 as shown above This circuit includes the upper interlocks of No 2 and the interlocks, *a*, of the current-limiting relay

On No 1 closing, the shunt coi of relay is connected in series with its operating coil The shunt plunger is held up and the series plunger is free to fall when the line current decreases to the pre determined limit When this occurs, interlock *a* opens the control circuit of No 1, and, after this contactor opens, the coil of No 2 is excited *via* interlocks *b* On No. 2 closing, a retaining circuit is established *via* the relay contacts of pressure governor This circuit is opened when the pressure rises to the upper limit.

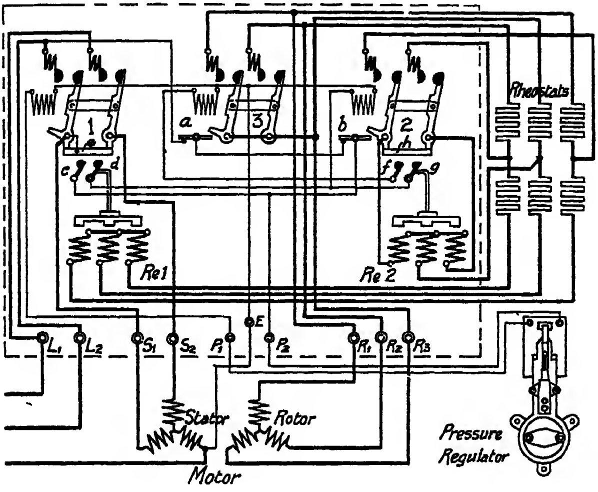


FIG 111.—Connections of Igranic automatic starter with pressure regulator, for three-phase motor with wound rotor

The operating-coil circuit of contactor No. 1, including the interlocking switches *a*, *b*, is controlled by the pressure regulator.

Contactors 2 and 3 are controlled by the current-limiting relays *Re* 1, *Re* 2, these relays actuating fingers *d*, *g*, respectively

Thus, when the rotor current decreases to the predetermined limit, relay *Re* 1 allows finger *d* to make contact with *e*, thereby completing the circuit to operating coil No 2 Contactor No 3 is energized in a similar manner (by means of the fingers *f*, *g* and contact strip *h* on contactor No 2) so that it can only be established when contactor No 2 is closed.

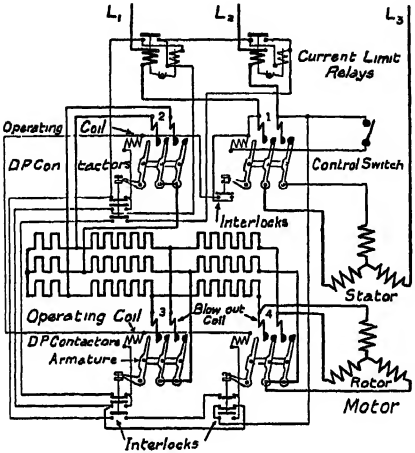


FIG 112—Connections of B T.-H. (Type TMC) automatic starter for three-phase motor with wound rotor.

Contactor No. 1 is energized by closing the control switch The interlocks of this contactor connect the shunt coil of current-limiting relay No 1 in series with the operating coil of contactor No. 2, thus preventing this contactor from closing until the series plunger of relay is released, which occurs when the line current decreases to a pre-determined value The shunt coil of relay is then short-circuited and No 2 contactor closes

By means of interlocks on this contactor a retaining circuit is established and the shunt coil of relay No 2 is connected in series with the operating coil of contactor No 3 This contactor closes when the line current decreases again to the pre-determined value Contactor No 4 is controlled, in a similar manner, by relay No 1 When No 4 closes the control circuit of Nos. 2, 3 and the relays is opened

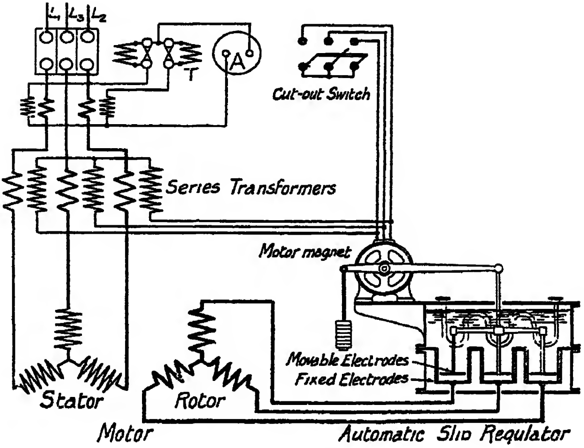


FIG. 113—Connections of Westinghouse automatic slip regulator for three-phase motor.

Slip regulators are necessary for induction motors driving flywheel-motor-generator sets which are used for load equalizing purposes in the Ilgner system of operating mine hoists and rolling-mill motors. In order to utilize the stored energy in the flywheel for load equalization the speed of the induction motor must decrease with an increase of load and *vice versa* This speed variation is obtained by means of a liquid rheostat in the rotor circuit. The movable electrodes are operated by an induction motor (called a "motor-magnet") with short-circuited rotor, the stator of which is supplied with current proportional to the line current The motor-magnet is so adjusted that, with normal load on the main motor, the torque lever is horizontal and a definite resistance is inserted in the rotor circuit of main motor Any change in the load alters the torque of motor-magnet and causes the electrodes to move either upwards or downwards, thereby increasing or decreasing the resistance in the rotor circuit

The liquid rheostat is provided with cooling coils for water circulation

An illustration of a regulator with its series transformers is given on p 191.

Alternating-current crane controllers have been developed for single-phase commutator motors and for two- and three-phase induction motors The types are not so numerous as those developed for direct-current crane motors, since it is not practicable to adapt the motors to the variety of service conditions to which D C motors are adaptable

For **single-phase repulsion** (or series) **motors** the controller is similar to that for a D C series motor except that the blow-out coil[1] is omitted—*see* Fig 114

Polyphase crane motors are generally of the wound-rotor type, but, in some cases, motors with high-resistance squirrel-cage rotors have been adopted for handling light loads and for the cross traversing motion. Motors having wound rotors are controlled by rheostats in the rotor circuit When drum-type controllers are adopted the resistance sections are cut out successively from the phases of rotor—*see* Fig 116

For **heavy-service cranes** a contactor-type starter, controlled by a master controller, is more suitable than a drum-type controller since the contactors are provided with magnetic blow-outs which cannot be fitted to the controller[1]

Brake magnets are shunt wound and are usually connected in parallel with the stator of motor The punchings constituting the fixed and movable cores are shaped to form three poles, and each pole is encircled with a coil For three-phase circuits the coils are star-connected for two-phase circuits one set of two coils is connected across one phase while the remaining coil is connected across the other phase

Limit switches may be of the main-current type or of the auxiliary type (B.T-H system) In the former case D P switches are necessary for three-phase and two-phase circuits, and S P switches for single-phase circuits Auxiliary limit switches are not affected by the supply system and are identical with those used with D C equipments—*see* pp 27, 33, 34

A **wiring diagram** for a three-phase, three-motor, crane, with main-current limit switches for hoisting and longitudinal travel, is given in Fig 118

[1] Drum-type controllers for A C motors cannot be provided with magnetic blow out in the same manner as controllers for D C motors owing to the eddy currents which would be induced in the solid metal parts by the alternating flux

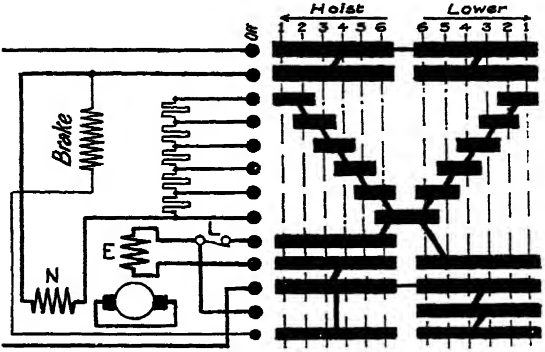


FIG. 114—Connections and development of reversing controller, for repulsion motor, with limit switch and brake magnet

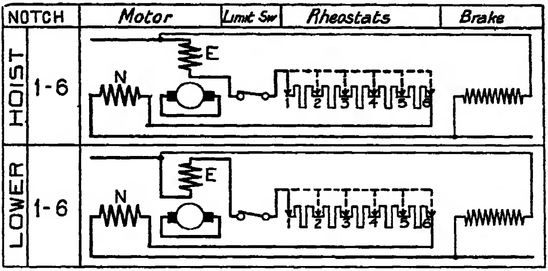


FIG 115—Combinations for Fig 114

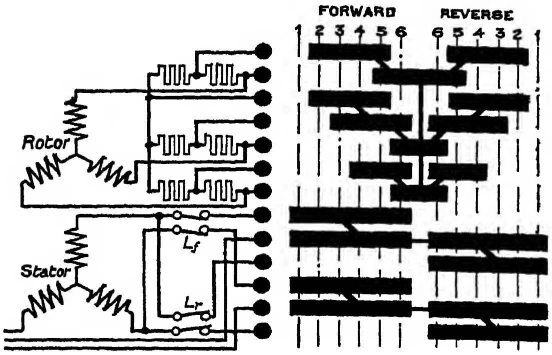


FIG. 116—Connections and development of reversing controller, for three-phase motor with wound rotor, arranged for use with limit switches for longitudinal travel motions

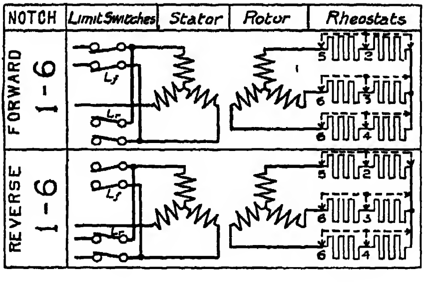


FIG. 117.—Combinations for Fig 116

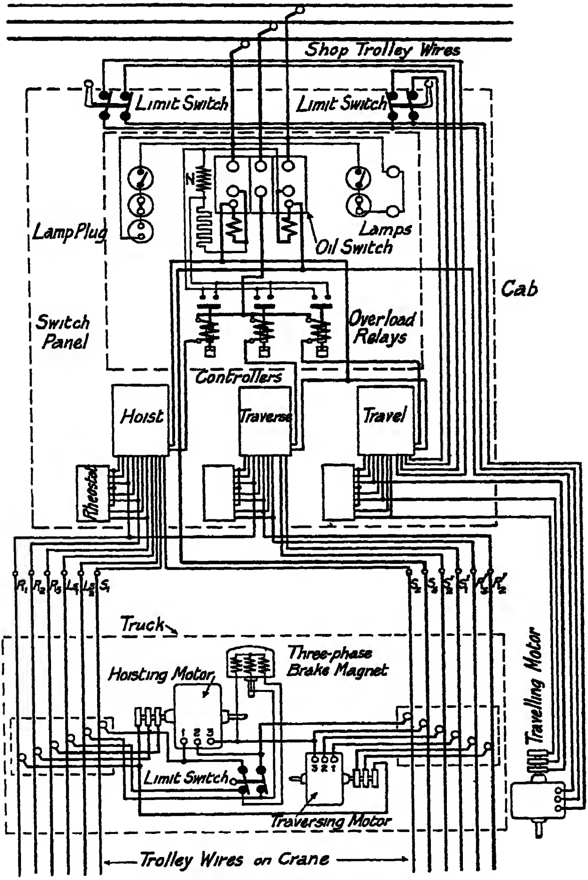


FIG 118 —Wiring for three-phase, three-motor crane, with limit switches and brake magnet.

SECTION 5

Power Transformers and Static Balancers

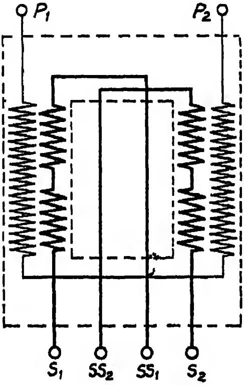


FIG. 119.

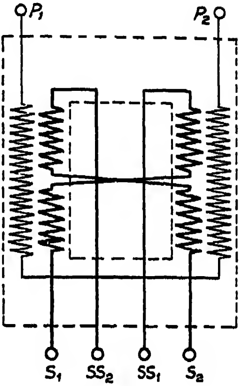


FIG 120

Connections of single-phase transformers for two-wire (Fig 119) and three-wire (Fig 120) circuits

The secondary windings and terminals are arranged to provide for series and parallel combinations when used on two-wire circuits. For series grouping connect SS_1 and SS_2; for parallel grouping, connect S_1 and SS_2, S_2 and SS_1

For three-wire circuits, connect SS_1, SS_2 to neutral wire In this case the secondary windings must be connected in accordance with Fig 116, in order that the out-of balance current shall not produce magnetic unbalancing

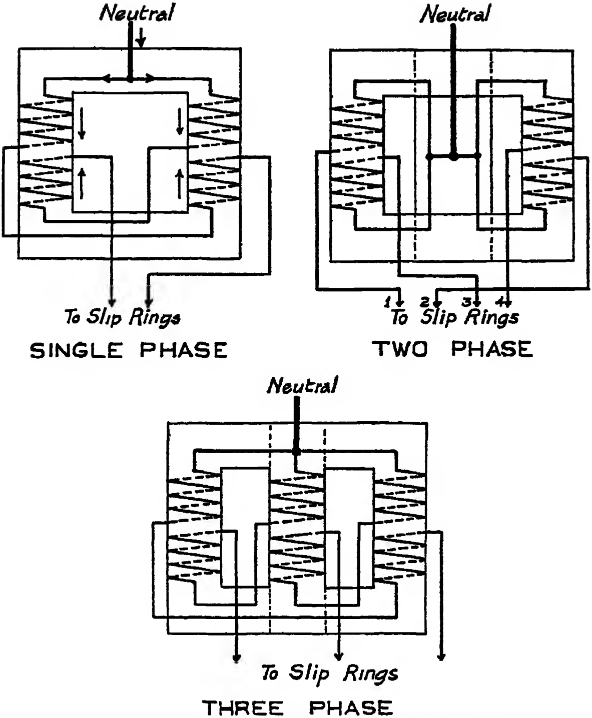


FIG. 121.—Connections of static balancers.

Static balancers are necessary when a three wire system is supplied from single direct-current generators without auxiliary balancer sets (*see* pp. 46, 56, 57). The balancer is virtually a single-winding transformer with a mid point tapping connected to the neutral wire. It is magnetized by alternating current (obtained from slip rings connected to tappings on the armature winding). The windings must be so interconnected that the out of balance current shall not magnetize the cores. The arrows in the diagram of the single-phase balancer indicate the direction in which the out of balance current circulates in the windings.

FIG 122.

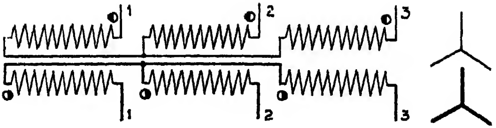


FIG 123

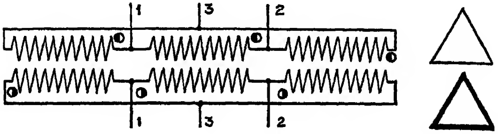
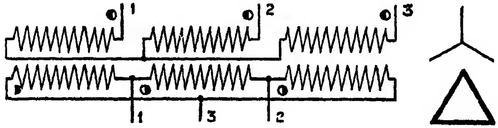


FIG. 124.



Connections of single-phase transformers for three-phase circuits Fig 122—Star-star, Fig 123—delta-delta, Fig 124—star-delta.

The distinguishing marks placed against the windings denote terminals at which the instantaneous direction of current is the same The marked (primary and secondary) terminals of a given transformer will therefore have *unlike* polarity

From these diagrams we obtain the following **rules for connecting-up single-phase transformers,** with marked terminals, on three-phase circuits—

(1) *For star connection* —Connect together the positive (or marked) terminal of each transformer to form the neutral point

Connect the line leads to the free (or unmarked) terminals

(2) *For delta connection* —Connect the positive (or marked) terminal of one transformer to the negative (or unmarked) terminal of the next transformer, etc, so as to form a closed circuit Connect a line lead to each of these interconnectors.

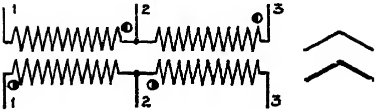


FIG 125 —Open delta (or " V ") connection of two single-phase transformers for three-phase circuits.

The " V " connection is obtained from the delta (Δ) connection by omitting one transformer The connection can, therefore, be used to obtain an emergency supply in the event of one transformer of a delta-connected group becoming disabled For the same heating, however, the output of the V-connected transformers will be only 57·7 per cent of that obtained with the delta-connected transformers The V connection is used with auto-transformer starters for induction motors and rotary converters (*see* pp 79, 80, 94, 149), while it is sometimes adopted with current transformers when the latter are used in combination with instruments or trip coils (*see* pp 112, 114, 119, 128).

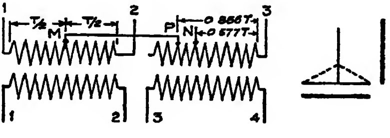


FIG 126 —Scott (or T) connection of two single-phase transformers for transforming three-phase power to two-phase power (or *vice versa*) The primary winding of one transformer (No 1) must be provided with a mid-point tapping, *M*, while that of the other transformer (No 2) must be provided with an 86 6 per cent tapping, *P*

The neutral point for the three-phase side may be obtained from a 57 7 per cent tapping, *N*, on transformer No 2.

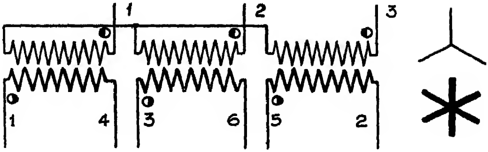


FIG 127.—Connections of single-phase transformers for three-phase/six-phase transformation—Diametrical connection.

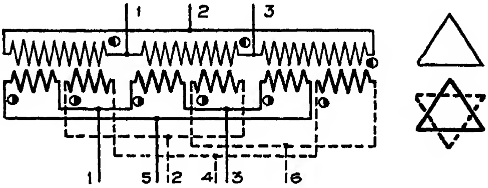


FIG 128.—Connections of single-phase transformers for three-phase/six-phase transformation—Double-delta connection on secondary side

Note to Figs 127, 128.—The above methods of obtaining six-phase current from a three-phase circuit are principally used in connection with rotary converters *See* pp 149, 150.

Internal connections of three-phase transformers.—In order that two three-phase transformers may be operated in parallel the following conditions must be satisfied—(1) the primary (line) voltage and voltage ratio of each must be the same, (2) the impedance voltage of each at full-load current must be the same, (3) the terminals of a given winding (primary or secondary) belonging to similar phases must have like polarity The importance of the last condition will be appreciated after a study of the diagrams of Fig. 129, which show alternative methods of arranging the internal connections From the vector diagrams given in this Figure it will be apparent that transformers connected according to the same group number may be operated in parallel provided that conditions (1) and (2) are satisfied, but transformers connected according to different group numbers cannot be paralleled even if the transformers are identical in every other respect. For instance, a delta/delta, group I, transformer may be operated in parallel with a star/star, group I, or a star/zig-zag,[1] group I, transformer of the same voltage and ratio; but it cannot be operated in parallel with a delta/delta, group II, transformer or, in fact, *any* group II or group III transformer

Standard methods of internal connections for three-phase and six-phase transformers have been developed by the American Institute of Electrical Engineers [2] These methods are included in the 1916 Standardization Rules and are shown diagrammatically in Figs 125, 126 Certain of the Rules relating to transformer connections are given on pages 109, 110, 111

[1] The zig zag or interconnected star method of connection is used for three-phase, four-wire, unbalanced systems

[2] Similar methods for three phase transformers were given in the 1912 Standardization Rules of the V D E

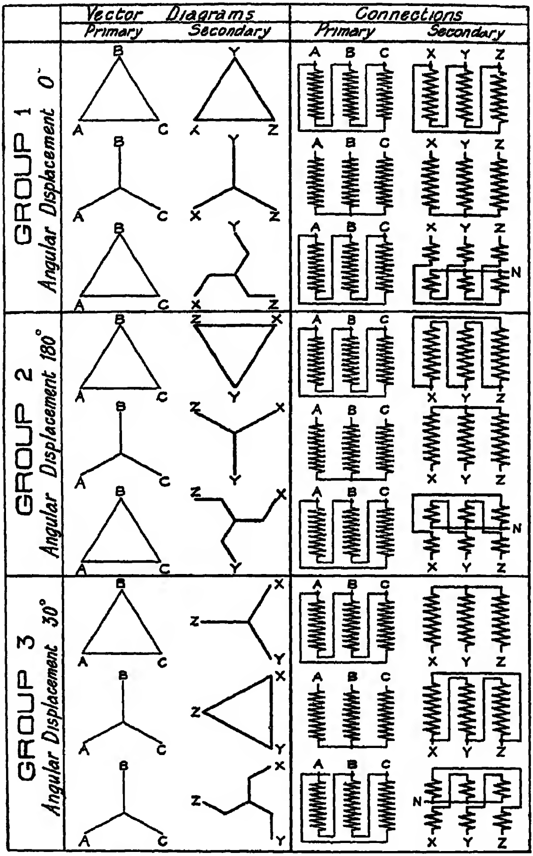


FIG 129 —Methods of arranging internal connections of three-phase transformers. The vector diagrams show the phase of the voltages.

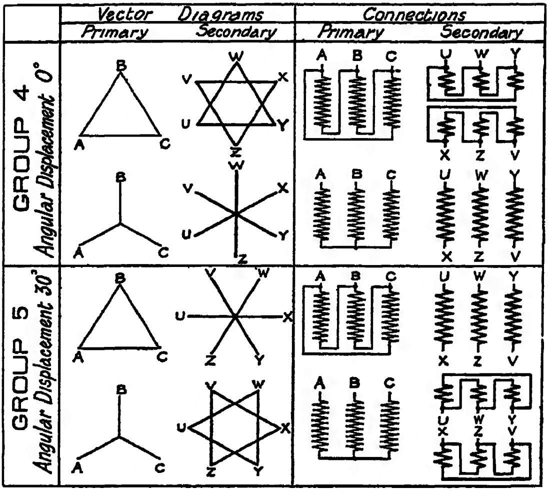


FIG 130 —Methods of arranging internal connections of three-phase/six-phase transformers The vector diagrams show the phase of the voltages

STANDARDIZATION RULES OF THE A I E.E TRANSFORMER CONNECTIONS[1]

(These rules do not apply to auto-transformers)

600. Diagrammatic Sketch of Connections.—The manufacturer shall furnish with each transformer a complete diagrammatic sketch of the internal connections, and all terminals and taps of the transformer shall be marked to correspond with letters and numbers in the sketch This sketch should preferably be on a metal plate on the transformer case

SINGLE-PHASE TRANSFORMERS

601. Marking of Leads.—The leads of single-phase transformers shall be distinguished from each other by marking

[1] Sections 601 to 611, relative to a specific scheme of marking the leads, are tentative only, subject to the adoption of a comprehensive scheme of marking the terminals of all classes of apparatus

the high-voltage leads with the letters *A* and *B*, and the low-voltage leads with the letters *X* and *Y*

The terminals (by terminals is meant the ends of the windings) shall be so marked that the potential difference in all windings at any instant shall have the same sign, that is, the potential difference between *A* and *B* shall have the same sign at any instant as the potential difference between *X* and *Y*[1]

In accordance with the above rule, the terminals of single-phase transformers shall be marked as follows—

602. (1) High- and Low-Voltage Windings in Phase

A———————*B*

X———————*Y*

603 (2) High- and Low-Voltage Windings 180 deg Apart in Phase:

A———————*B*

Y———————*X*

606. Neutral Lead.—Where a neutral lead is brought outside the transformer case, it shall be lettered *N*.

THREE-PHASE TRANSFORMERS

608. Marking of Leads.—Three-phase transformers ordinarily have three or four leads for high-voltage and three or four leads for low-voltage windings To distinguish the various leads from one another, and also to distinguish between the various phase relations obtainable, the three high-voltage leads should be lettered *A*, *B* and *C* and the three low-voltage leads *X*, *Y* and *Z*

For transformers having six-phase secondaries the primary leads should be lettered *A*, *B* and *C* as above, and the secondary leads, *U*, *V*, *W*, *X*, *Y*, and *Z*

The letters shall be so applied to the transformer terminals that if the phase sequence of voltage on the high-voltage side is in the order of *A* to *B* to *C*, it is in the order of *X* to *Y* to *Z*, etc, on the low voltage side This arrangement is represented by the diagrams (Figs 125, 126), which show the various common angular displacements between high- and low-voltage windings of standard transformers In addition it should be distinctly stated, preferably on the rating plate, in which of the groups, given in the diagrams, the transformer belongs

609. The rules given above for single-phase transformers in regard to the neutral tap (*see* § **606**), and also in regard to internal connections (*see* §§ **601** to **605**), are applicable to three-phase transformers and six-phase transformers

610. Angular Displacement.—The angular displacement between high- and low-voltage windings is the angle in the

[1] To test the correctness of single phase markings, connect *A* to *X* and apply voltage to the high voltage winding *A-B* Voltage *B-Y* must be numerically less than voltage *A-B*

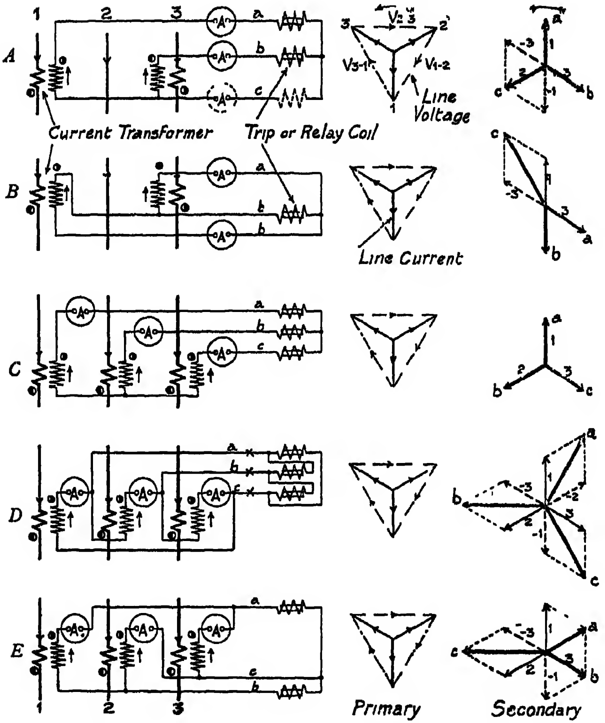
diagrams (Figs. 125, 126) between the lines passing from the neutral point through *A* and *X* respectively for three-phase transformers and through *A* and *U* for six-phase transformers Thus, in Group 1, the angular displacement is zero degrees; in Group 2, the angular displacement is 180° and in Group 3, the angular displacement is 30°.

611. Parallel Operation.—Three-phase and six-phase transformers marked as above may be operated in parallel, by connecting similarly marked terminals together, provided their ratios, voltages, resistances, reactances and angular displacements are such as to permit parallel operation.

SECTION 6

Instruments, Instrument Transformers and Relays

Methods of inter-connecting current transformers for three-phase circuits—Methods of connecting wattmeters, watt-hour meters and power-factor indicators for single and polyphase circuits—Connections of overload and reverse power relays for single and polyphase circuits—Synchroscopes—Connections for synchronizing single and polyphase machines



Connection Diagrams
FIG 131

Vector Diagrams
FIG 132

Methods of connecting current transformers and trip (or relay) coils for three-phase circuits

NOTE —The vector diagrams (Fig 132) have been drawn for unity power-factor in the primary circuit, and the internal phase angle for the transformers has been considered as 180°.

Methods of connecting current transformers and trip (or relay) coils for three-phase circuits.

Five methods are possible, as shown in Fig 131, two of which are suitable for three-wire systems, operating with insulated neutral, and the remaining three are suitable for four-wire systems, or for three-wire systems with earthed neutral.

Referring to Fig 131:

Diagram *A* shows the method—known as the "*reversed-V" connection*—usually adopted for three-wire unearthed systems Under normal conditions the currents in the secondary leads are equal and are 120° apart.

Diagram *B* shows a method (which is not recommended) by means of which protection can be obtained by the use of one trip coil The two current transformers are V-connected and the trip coil is connected in the common lead, *b*, the current in this lead being $\sqrt{3}$ ($=1{\cdot}73$) times that in each of the secondary windings

Diagram *C* shows the method usually adopted for three-wire systems with earthed neutral and for four-wire systems. The transformers and trip coils are star-connected, the currents in each secondary lead, under normal conditions, being equal and 120° apart

Diagrams *D* and *E* show methods which are occasionally adopted In method *D* the transformers and trip-coils are delta-connected The currents in leads *a*, *b*, *c* (marked *x*) are $\sqrt{3}$ times the current in each secondary winding and are in phase-opposition with the line voltages (at unity power-factor) This feature enables a single-phase wattmeter to be used for measuring the power in the circuit provided that the loads are balanced

The method shown at *E* is known as the *Z-connection* and is adopted when a D P relay is to be used on a system with an earthed neutral

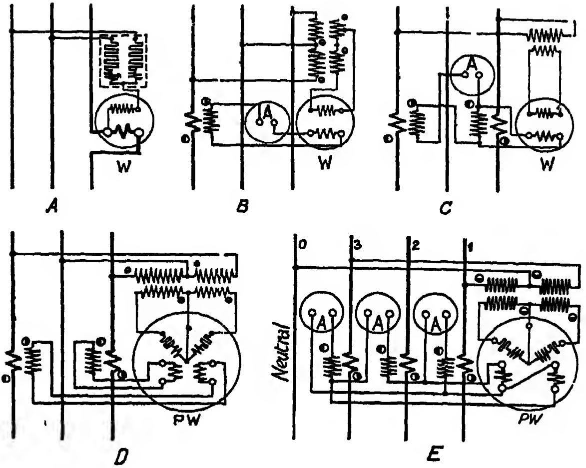


Fig. 133.—Connections of indicating wattmeters for three-phase circuits.

Diagrams *A*, *B*, *C* show alternative connections for *balanced* loads. In these cases a single-phase wattmeter, specially calibrated, is used With method *A* the voltage impressed on potential coil of wattmeter is equal to the *phase* voltage [i e $1/\sqrt{3}$, or 57·7 per cent, of the *line* voltage] of the system and is in phase with the current in the current coil [1]

With method *B* the phase-coincidence of currents in the wattmeter coils is obtained by means of two potential transformers, the primaries of which are V-connected The secondaries are connected in series. one terminal of the potential coil of wattmeter is connected to a mid-point tapping on one transformer and the other terminal is connected to the free end of the other transformer Thus the voltage impressed on the potential coil is 86·6

[1] Assuming unity power-factor.

per cent ($=\sqrt{3}/2$) of the line voltage and is in phase with the current in the current coil [1]

With method *C*, two V-connected current transformers are used, and the current coil of wattmeter is connected in the common lead Thus this current is in phase[1] with the voltage between the lines to which the current transformers are connected. Refer to Fig. 128, *B*.

Diagrams *D*, *E* show alternative methods for *unbalanced* loads

Diagram *D* shows the method usually adopted for measuring power on a three-wire system. It is known as the "*two-wattmeter*" method, and the diagram shows a *polyphase wattmeter* in which two wattmeters are combined so that only a single moving system is required.

Diagram *E* shows the method adopted for a four-wire system The theory and proof of the method is given in the author's *Theory and Practice of Alternating Currents* (Pitman).

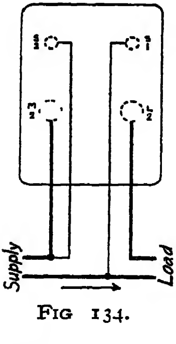


FIG 134.

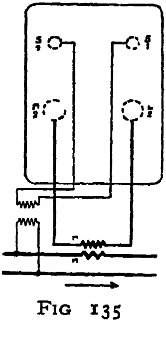


FIG 135

Connections of watt-hour meters for measurement of energy on single-phase, two-wire circuits

[1] Assuming unity power factor and neglecting the internal phase angles of the transformers

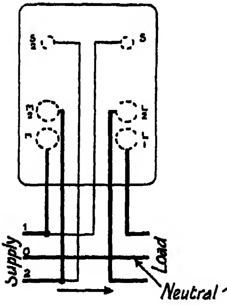


Fig 136.

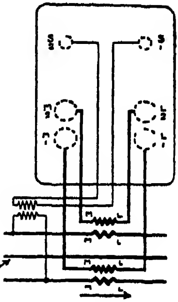


Fig 137

Connections of watt-hour meters for measurement of energy on single-phase, three-wire circuits

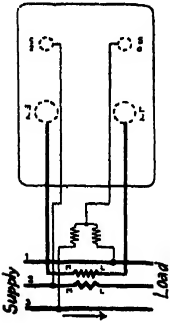


Fig 138.

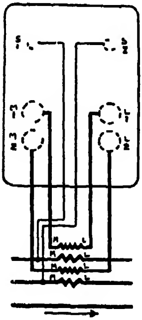


Fig 139

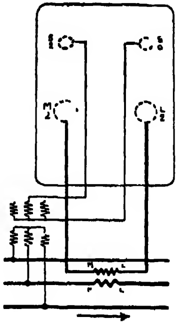


Fig 140

Connections of watt-hour meters for measurement of energy on three-phase, three-wire circuits with *balanced* loads.

Note to Figs. 136–140.—In the instruments shown in Figs 136, 137 the current coils are wound in two sections which are so connected that the resultant flux is due to the sum of the currents in the outers

Fig. 138 is analogous to Diagram *A*, Fig. 133. The voltage impressed on the potential (shunt) coil of meter is equal to the *phase* voltage of the system. This voltage is obtained by connecting the potential coil to two reactances (each having an inductance equal to that of the potential coil) so as to form a star-connected system.

Fig. 139 is analogous to Diagram *C*, Fig. 133. The current coils of meter are wound in two sections (as in a single-phase, three-wire meter), which are so connected that the resultant flux is due to the (vector) difference of the currents in lines 1 and 2. The potential coil is connected across these lines.

Fig 140 refers to a high-voltage circuit. The voltage impressed on the potential coil of meter is proportional to the phase voltage of the system and is obtained from a three-phase potential transformer.

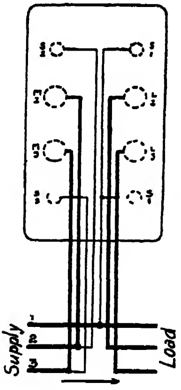


Fig 141

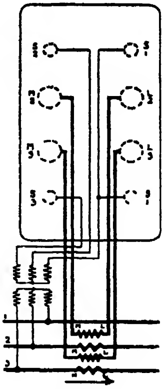


Fig 142

Connections of watt-hour meters for measurement of energy on three-phase, three-wire circuits with *unbalanced* loads

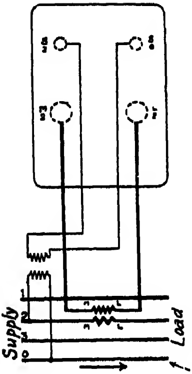


Fig 143

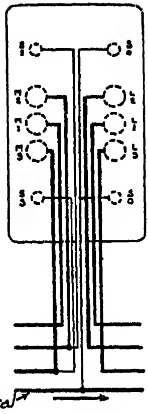


Fig 144

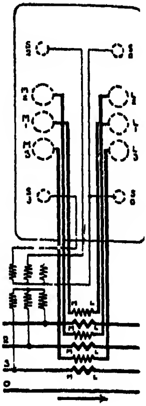


Fig. 145

Connections of watt-hour meters for measurement of energy on three-phase, four-wire circuits with balanced and unbalanced loads.

Note to Figs. 134–145.—These diagrams refer to Ferranti switchboard meters when viewed from the *front* The letters *M*, *L*, *S* denote, respectively, the main, load and shunt terminals of meters and transformers The arrow in each diagram indicates the direction of power in the circuit

Single-phase meters are shown in Figs 134, 135, 136, 137, 138, 139, 140, 141, and polyphase meters—consisting of two single-phase elements mechanically coupled together—are shown in Figs 141, 142, 144, 145

Figs 134, 136, 138, 139, 141, 144 refer to low-voltage circuits

Figs 135, 137, 140, 142, 143, 145 refer to high-voltage circuits

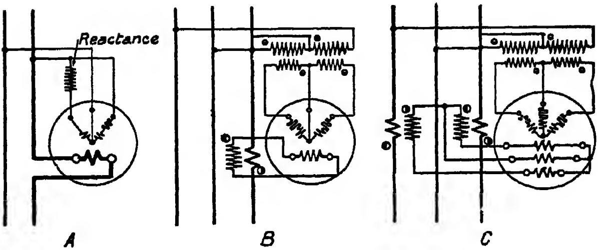


FIG 146 —Connections of power-factor indicators for single-phase and three-phase circuits

Diagram *A* shows the connections for a single-phase instrument having a (fixed) current coil and two (moving) potential coils A non-inductive resistance (shown internal to the instrument) is connected in series with one coil ; a reactance (shown external to the instrument) is connected in series with the other coil, and the combinations are connected in parallel across the circuit With some instruments a condenser is used instead of a reactance

Diagram *B* shows the connections for a three-phase instrument for use on *balanced* loads, while diagram *C* refers to an instrument for *unbalanced* loads In this case the instrument must have three current coils and three potential coils

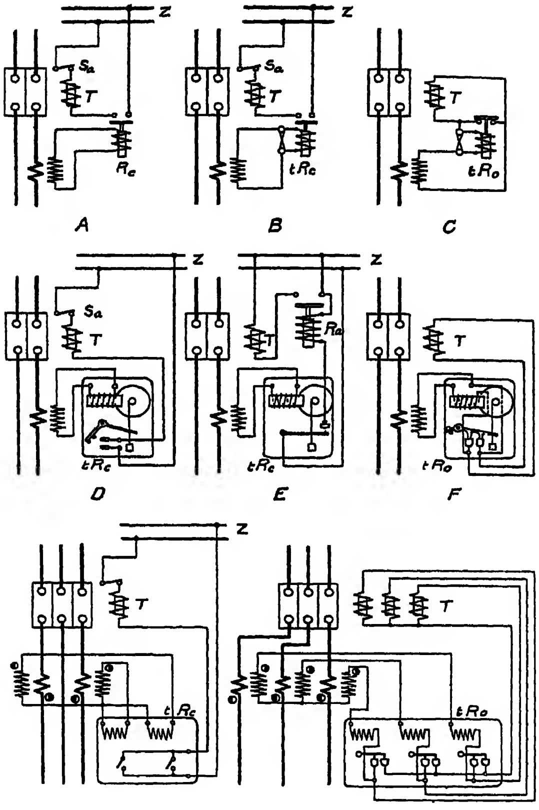


FIG 147.—Connections of current transformers overload relays and trip coils

[References Rc, instantaneous circuit closing relay, tRc, time limit circuit closing relay, tRo, time limit circuit opening relay, Ra, auxiliary relay, T, trip coil, Sa, auxiliary switch—operated by mechanism of oil switch—for opening trip coil circuit, Z, auxiliary D C supply for trip coils]

Methods of connecting overload relays and trip coils (*see* Fig 147).

Overload relays may be classified as follows—(1) instantaneous plunger-type; (2) time-limit plunger type, in which the operating coil is normally shunted by a fuse (*see* Fig 243, p 194) thus giving the relay a time-limit characteristic[1], (3) induction (rotating disc) type (*see* Fig 244) which has a natural time limit, varying, for a given setting, approximately inversely as the current in the operating coil[2]

In each case the relay contacts are arranged so that, when relay operates, the trip coil is connected either to an auxiliary circuit (circuit-closing contacts) or in the secondary circuit of the current transformer, the trip coil being normally short-circuited (circuit-opening contacts)

Referring to Fig. 147—

Diagram *A* shows the connections for a circuit-closing, plunger type, instantaneous relay When relay operates, the trip coil *T*, is connected to the auxiliary D.C. circuit *Z*, and when the oil switch opens, the trip-coil circuit is opened by an auxiliary switch, *Sa*, operated by the switch mechanism.

Diagram *B* shows the connections for a circuit-closing plunger type, time-limit relay

Diagram *C* shows the connections for a circuit-opening, plunger type, time limit relay. The trip coil, *T*, is normally short-circuited by the relay contacts, and the relay coil is shunted by a fuse When an overload occurs the fuse is blown and the secondary current passes through the relay coil The operation of relay removes the short-circuit from the trip coil, thus connecting this coil in the secondary circuit

Diagrams *D* and *E* show the connections for circuit-closing, induction-type relays In Diagram *E* the relay contacts are considered to be incapable of carrying the current required to operate the trip coil, so that an auxiliary relay *Ra* is required for closing the trip coil circuit

Diagram *F* shows the connections for a circuit-opening, induction-type relay

Diagrams *G* and *H* relate to induction-type relays on three-phase circuits At *G* are shown the connections for a D.P. circuit-closing relay, which is suitable for a circuit with unearthed neutral, while at *H* is shown a T P. circuit-opening relay, which is suitable for a circuit having the neutral earthed In this case three trip coils are necessary If, however, the circuit-closing type of relay is adopted only one trip coil is required

[1] *See* page 174 for characteristic curves
[2] *See* page 173 for characteristic curves

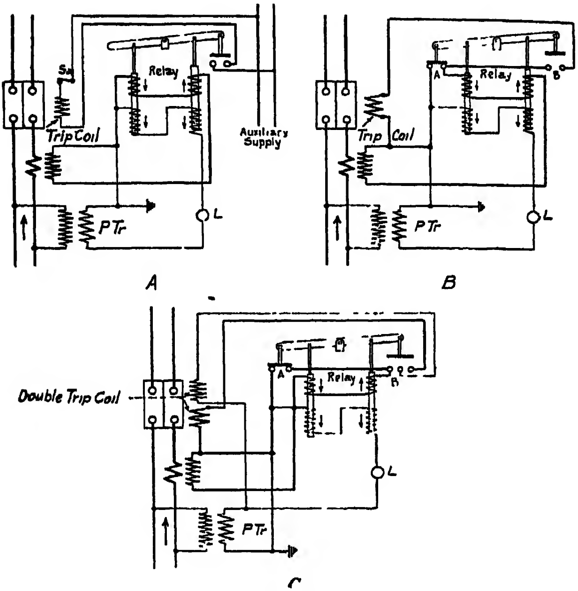


FIG 148 —Methods of connecting reverse-power relays for single-phase circuits

The diagrams have been drawn for the double differential type of relay (B T -H system) with shunt and series coils The arrows indicate the direction of current corresponding to forward power · with reverse power the current in the current coils reverses, and the beam is tilted in the clockwise direction

Diagram *A* shows the method of connecting a circuit closing relay—which type should be used for generators—the auxiliary supply for tripping purposes being obtained from the excitation circuit of the machines

Diagrams *B* and *C* show alternative methods of connecting circuit opening relays; the former being suitable for switches with light tripping mechanism and the latter for switches with heavy tripping mechanism, or in cases where it is desired to utilize the full sensitiveness of the relay, and no auxiliary supply is available With each form of circuit opening relay, the contacts *B* are closed before the contacts *A* are opened

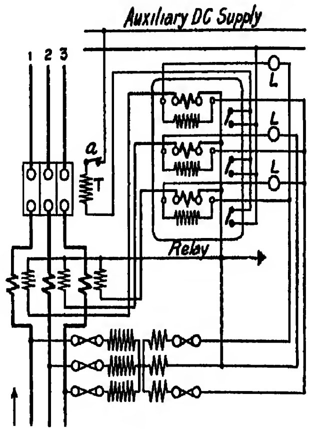


FIG 149.

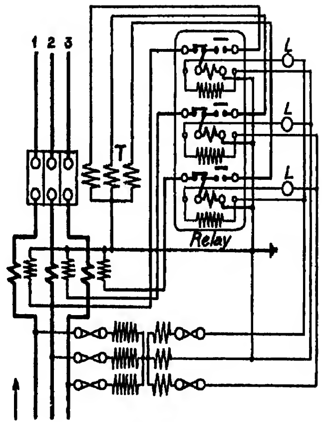


FIG. 150.

Connections of B T -H reverse-power relays for three-phase circuits. Fig 149 refers to a circuit-closing relay; Fig 150 refers to a circuit-opening relay.

The **methods in general use for synchronizing alternators** are—(1) the lamp synchronizer, with voltmeter, (2) the rotating field synchroscope

The former, when used with single-phase machines, gives no indication as to which of the two machines is the faster. The lamps may be connected so that they are either dark or bright at the moment of synchronizm—*see* Figs. 154, 155. With three-phase machines the lamps may be arranged—*see* Fig 156—so that the order in which they light up indicates whether the incoming machine is fast or slow.

In the **Weston synchroscope**—*see* Figs. 151 *A*, 247—a phase indicator is combined with the synchronizing lamp. The phase indicator is constructed on the lines of a wattmeter it is fitted with an opal dial in *front* of the pointer and a synchronizing lamp *behind* the pointer The fixed coils, together with the inductive resistances, *r*, and the non-inductive resistance, *R* (Fig 151 *B*), are connected to the machine on load; while the moving coil, with a condenser, *C*, in series, is connected to the incoming machine The lamp is supplied from both machines by means of a synchronizing transformer, *Tr*. When the machines are in exact synchronism the pointer coincides with the central mark on dial and the latter is brightly illuminated If the frequencies differ, the lamp will flicker and the pointer will deflect to right and left alternately, but due to the combination of the lamp with the instrument, only alternate deflections of the pointer are visible. In consequence the pointer appears to be revolving in one direction or the other, according to whether the incoming machine is fast or slow.

Rotary field synchroscopes are of either the motor or the phase-meter (rotating vane) types.

The motor type of instrument—Fig 152 *A*—consists of a stator—with a single-phase winding, which is connected to the machine on load—and a rotor (with a two-phase winding) to the spindle of which a pointer is attached. The rotor is supplied with split-phase current from one phase of the incoming machine.

When synchronizing machines by a two-pole (single-ended pointer) synchroscope for the first time, it is necessary to use lamps in conjunction with the synchroscope to ascertain whether synchronism corresponds to the vertically-upwards (normal) position or to the vertically-downwards position of the pointer Should the latter be the case a reversal of the leads connected to terminals *AB* (Fig 152 *A*) will put matters right

To enable one synchroscope to be used for a number of machines, the connections between the former and the latter are made by means of plugs and plug receptacles The plugs may have two, three, four or six contacts according to the system of connections adopted, (*see* Figs 154-159) Views of a plug and receptacle are given in Fig 249, and the methods of interconnecting the contacts are shown in Fig 153

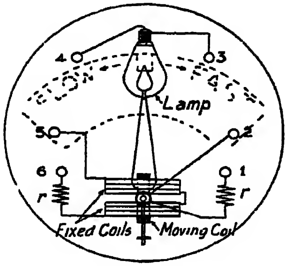


FIG 151*A*

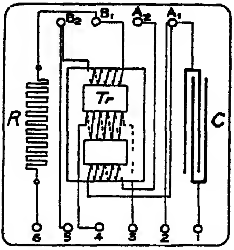


FIG 151*B*

Internal connections of Weston synchroscope and auxiliary box

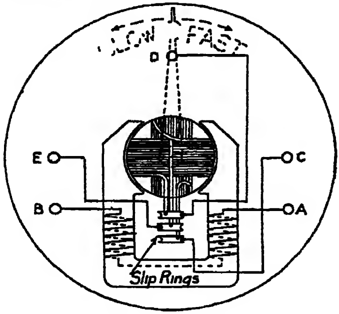


FIG 152*A*.

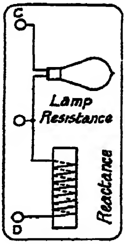


FIG 152*B*.

Internal connections of B T -H rotary-field synchroscope and auxiliary (phase-splitting) box

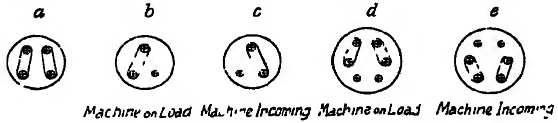


FIG 153 —Connections of 3-, 4- and 6-point synchronizing plugs

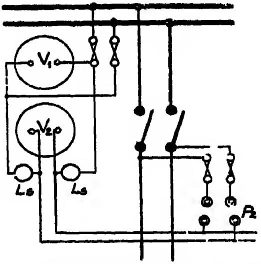


FIG 154.—Connections for synchronizing single-phase, low-voltage machine with bus-bars, using lamps
V_1, bus-bar voltmeter,
V_2, incoming machine voltmeter,
Ls, synchronizing lamps,
P_2, 4-point plug receptacle (plug is shown at *a*, Fig. 153).
Note.—Lamps are dark at moment of synchronizing.

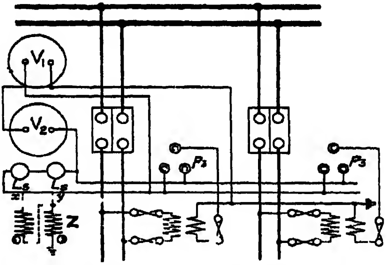


FIG. 155 —Connections for synchronizing two single-phase, high-voltage machines, using lamps
Each machine is provided with a potential transformer
The full lines to the synchronizing lamps, *Ls*, show the connections for "dark" synchronizing. For "bright" synchronizing a 1 1 potential transformer must be connected (reversed) in the synchronizing circuit This transformer is shown at *Z* and is connected, as shown by dotted lines, to the points *x*, *y* of the synchronizing circuit
The plugs are of the three-point type, and their connections are shown at *b*, *c*, Fig 153

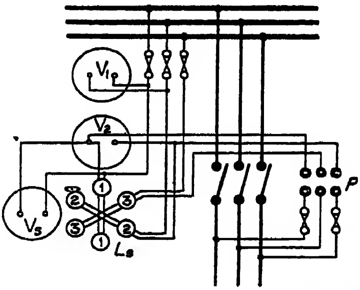


FIG 156 —Connections for synchronizing three-phase, low-voltage, machine with bus-bars The lamps are connected according to the method developed by Messrs. Siemens, the order in which the lamps light up indicating whether the incoming machine is fast or slow At synchronism, lamps 1 are dark, and lamps 2, 3 are equally bright.

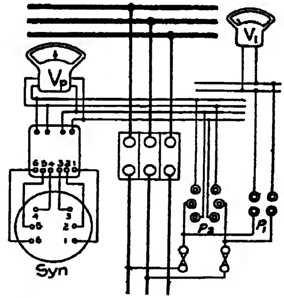


FIG 157 —Connections of Weston synchroscope and Everett-Edgcumbe paralleling voltmeter for low-voltage, three-phase machine

Two plug receptacles—one four-point (for machine voltmeter V'_1) and one six-point (for the synchroscope)—are necessary for each machine, the connections of the plug receptacles being the same for all machines The plug contacts for the machine on load and the incoming machine, however, are connected differently, as shown in Fig 153, *d, e*

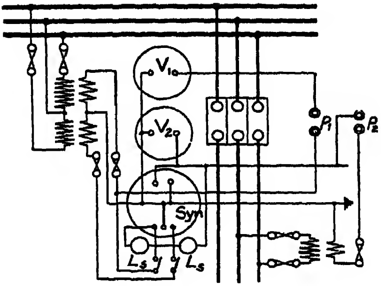


FIG. 158.—Connections for synchronizing three-phase high-voltage machine with bus-bars using the phase-meter, or rotating vane, type of synchroscope

P_1, 2-point plug receptacle for bus-bar voltmeter, P_2, 2-point plug receptacle for synchroscope (incoming machine).

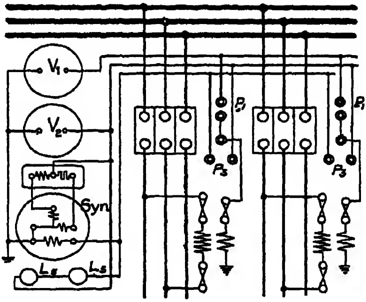


FIG 159.—Connections for synchronizing two high-voltage, three-phase machines using rotary field (motor type) synchroscope (B T.-H system)

P_1, 2-point plug receptacle for bus-bar voltmeter P_3, 3-point plug receptacles for synchroscope

For connections of plugs *see* Fig 153, *b,c.*

SECTION 7

Leakage Protective Systems for Direct-current and Alternating-current Circuits

Leakage protective detectors and indicators for D C. and A.C. mining installations—Core-balancing leakage protective system for three-phase circuits—Current-balancing protective system for transformers and alternators—Voltage balancing protective system for feeders—Split-conductor protective system for feeders—Auxiliary sheath protective system for feeders.

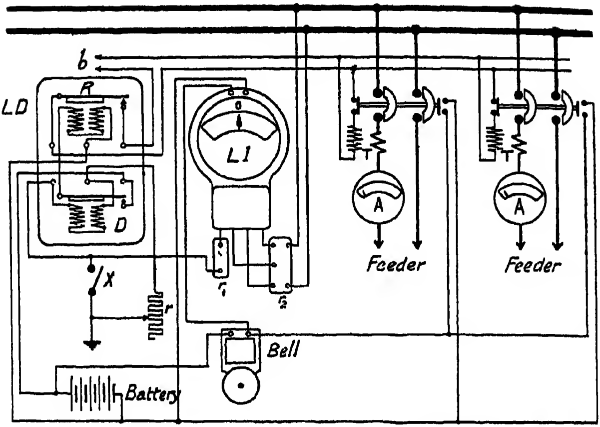


FIG. 160—Connections of B T-H leakage-protective detector and leakage indicator for D C circuits [B T-H Co]

The leakage detector, *LD*, consists of a very sensitive relay, *D*, and an auxiliary relay, *R*, for controlling the tr p coils of the circuit breakers The sensitiveness of the detector-relay may be adjusted by the resistance *r*, while the relay may be cut out of action by the switch *X*

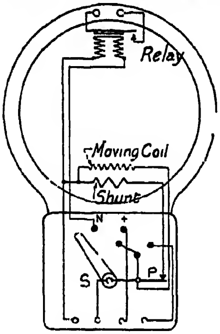


FIG 161

The internal connections of the leakage indicator, *LI*, are shown in Fig. 161 This instrument consists of a sensitive moving-coil ammeter—which is normally shunted—a special switch, *S*, and a relay for controlling a bell circuit For normal working the switch (S) occupies position *N* for testing the insulation resistances of each side of system the switch is placed in the " + " and " – " positions, the sensitiveness being increased by open-circuiting the shunt at *P*.

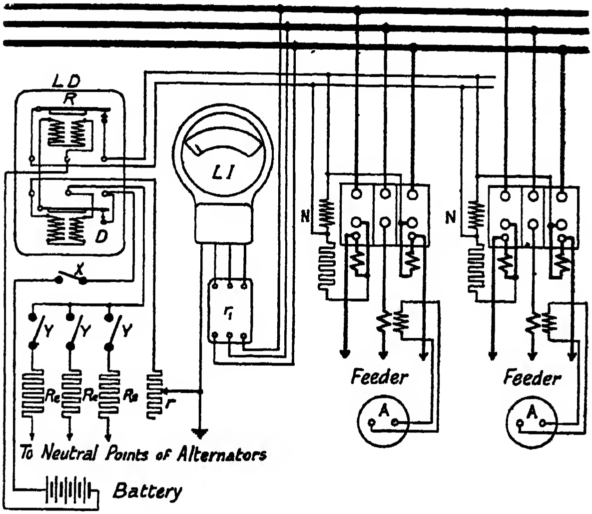


FIG 162 —Connections of B.T -H leakage-protective detector and leakage indicator for three-phase A C circuits [B T -H Co]

The leakage detector *LD* consists of a very sensitive relay *D* and an auxiliary relay *R* for actuating the no-volt releases of the oil switches The neutral points of the generators are connected to the relay through limiting resistances, *Re*, and S P switches, *Y* A further adjustable resistance, *r*, is connected in the detector-relay circuit The switch *X* is provided for the purpose of cutting out the auxiliary relay, *R*, when connecting feeders to the bus-bars, thus preventing the detector tripping the switches due to momentary capacity current

The magnitude of the leakage current is limited by the resistances employed in series with the detector, thus on a severe fault to earth occurring, it is impossible that more than a small fraction of an ampere can flow to earth

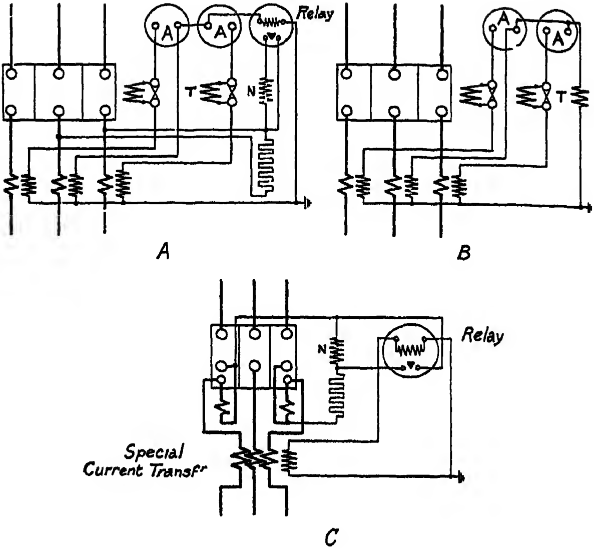


FIG 163 —Connections of B T -H selective (core-balancing) leakage protective system for three-phase, three-wire circuits

In diagrams *A*, *B*, the current transformers, trip coils and ammeters form a star-connected circuit The two neutral points are connected through either a relay (as in diagram *A*) or a special trip coil (as in diagram *B*) Under normal conditions no current is carried by this neutral wire, but on the occurrence of a fault, a current proportional to the leakage passes through the relay or trip coil

In diagram *C* a special current transformer—having three primary windings and one secondary winding, all wound on a common core—is adopted

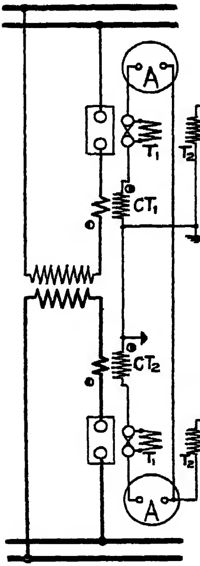


FIG 164.

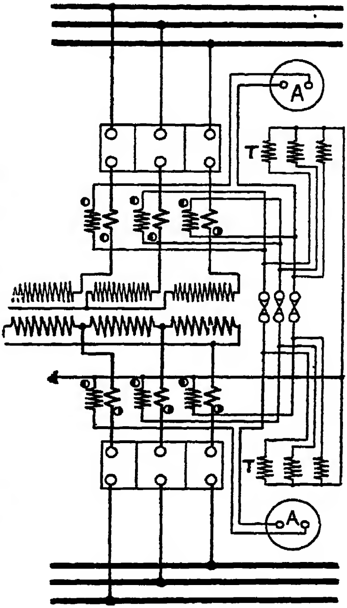


FIG 165.

Connections of current-balancing (Merz-Price) system of protection for single-phase and three-phase transformers

The ratios of transformation of the current transformers inserted in the primary and secondary of main transformer are chosen so that each transformer gives the same secondary current, and this normally circulates in the secondary circuit of the current transformers. Trip coils (T_1, T, Figs 164, 165) or relays are connected to points in the secondary circuit between which under normal conditions, no potential difference exists. If the current balance is disturbed, due to an internal fault in the transformer a current proportional to the fault current will be forced through the trip coils, thereby operating both oil switches.

To protect the transformer against overload, series trip coils (T_1 Fig 164) with time limit fuses may be connected in the secondary circuit. An alternative method, which dispenses with the series trip coils is to connect time limit fuses in the secondary circuit between the points to which the shunt trip coils are connected—*see* Fig 165.

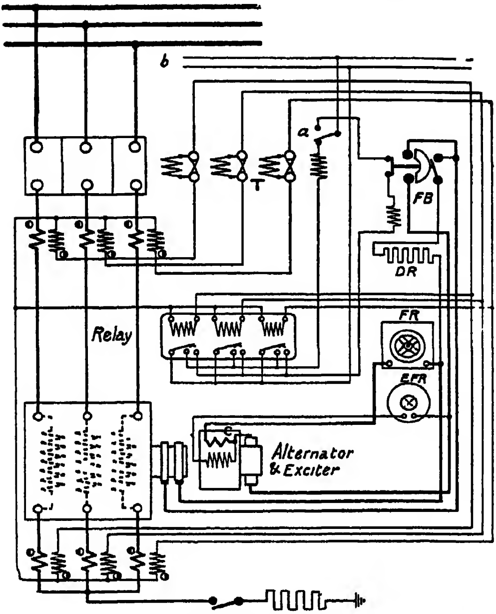


FIG 166—Connections of current balancing (Merz-Price) system of protection for three-phase alternator

Similar current transformers are inserted at the ends of each phase, and the secondary windings are connected so that the natural secondary current normally circulates A triple-pole leakage-protective relay is connected to points between which, under normal conditions, no potential difference exists If the alternator develops a fault, the currents are unbalanced and relay is operated In operating, the relay closes the tripping circuits of the oil switch and the field circuit breaker *FB* but the latter is interlocked with the oil switch (by means of auxiliary switch *a*) so that its trip coil is not energized until the oil switch has disconnected the machine from the bus-bars

The field circuit breaker (*see* Figs 239, 240, p 191) is fitted with a switch for cutting-in the discharge resistance, *DR*, and also an auxiliary switch for opening the trip-coil circuit.

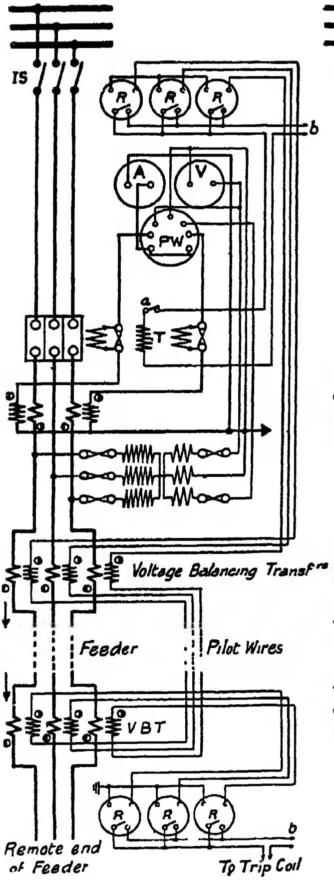


FIG 167

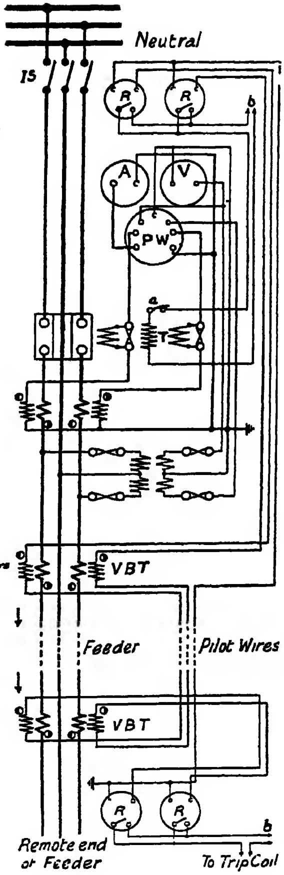


FIG 168

Connections of Merz-Price leakage protective system for three-phase (Fig 167) and two-phase (Fig 168) feeders.

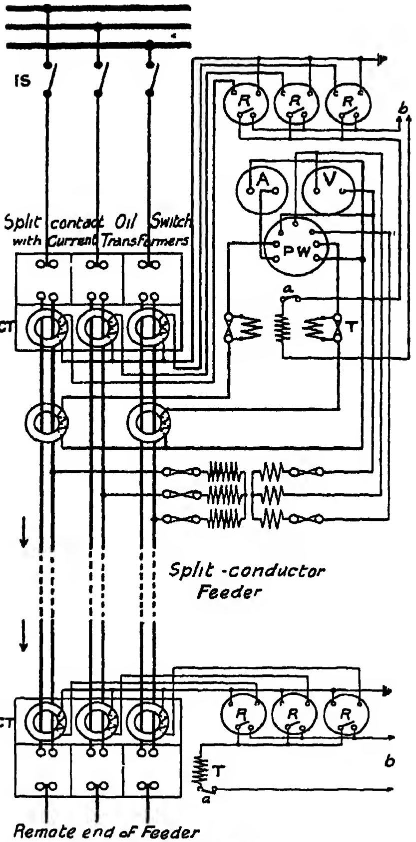
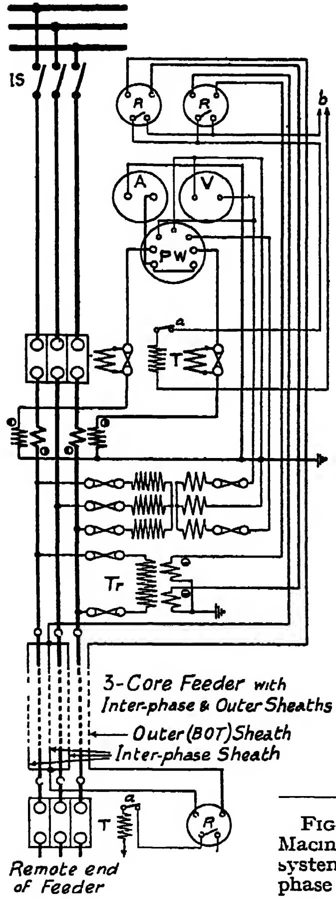


FIG. 169 —Connections of Merz-Hunter (split-conductor) system of protection for three-phase feeder

NOTE —A trip-pole relay suitable for use with the protective systems of Figs 167, 169 is shown in Fig 245, p 195.



The diagram shows the Bowden-Thompson leakage protective system applied to a three-phase trunk feeder. The system requires the use of a special cable with sheaths (*see* Fig 171). Each sheath is maintained at a slight voltage above earth by means of a transformer, *Tr*, with double secondary windings which are connected in opposition so that normally no current circulates in the circuit comprising the relays, sheaths and secondary windings On the occurrence of an earth fault, the balance is disturbed and the relays are operated If a fault occurs between the phases, *but not to* earth, the potential of the inter-phase sheath is raised, and a current is forced through the relay circuit, thus operating the relays and tripping the oil switches at both ends of the feeder

FIG 170 —Connections of Macintosh-Bowden-Thompson system of protection for three-phase feeder

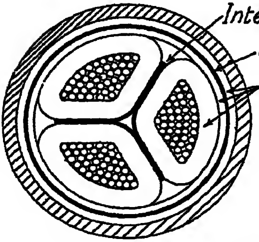


FIG 171 —Cross section (*not to scale*) of Macintosh cable (Bowden-Thompson system) with inter-phase and outer (B O T) sheaths

Notes on systems of protection for feeders

The *Merz-Price System* (Figs 167, 168) requires either current-balancing or voltage-balancing transformers with pilot wires and relays Voltage-balancing transformers are usually adopted; they are so adjusted that when the primary currents at each end of the feeder are equal the secondary voltages are balanced against one another and no current is carried by the pilot wires. On the occurrence of a fault in the feeder, the voltage balance is disturbed and a current circulates through the pilot wires and relays

The *Merz-Hunter (or split-conductor) System* (Fig 169) requires, for underground cable systems, the use of a special cable—cross-sections of which are shown in Figs 254, 255—in which the conductors of each phase are divided into two sections and insulated from each other The sections of each phase are connected to the oil switches through differential current transformers *SCT* (Fig 169) If the division of current between the sections of each phase is affected, due to a fault in feeder, a current—proportional to the fault current—is induced in the secondary of current transformer, and the relays are operated To obtain the full advantages of this system of protection it is necessary to adopt split-contact oil switches as shown in Fig 169

The system does not require the use of pilot wires and is applicable to overhead lines by a special arrangement of the conductors

The *Bowden-Thompson System* (Fig 170) requires the use of a special cable, but does not require the use of pilot wires or current transformers Moreover, the system does not involve the balancing of currents or voltages, such as is required for the above systems The operation of the relays is, therefore, unaffected by surges or switching operations

SECTION 8

Alternating-current Switch-gear and Switch Panels

Hand-operated and electrically-operated oil switches—Field-discharge switches—Switch panels for three-phase alternators (insulated and earthed neutral), motor-generators, rotary converters; motor-converters, two-phase feeders; three-phase feeders for systems operating with insulated and earthed neutrals.

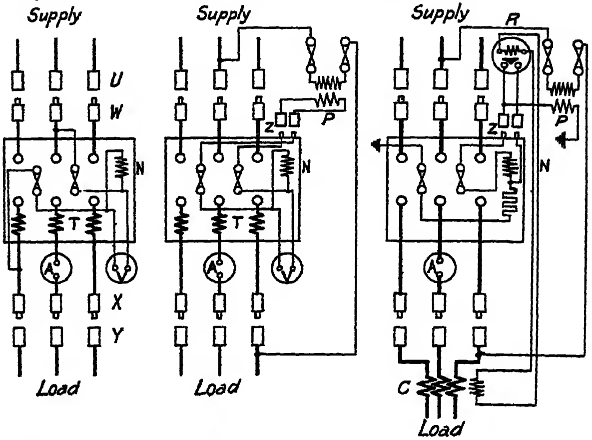


FIG 172. FIG 173 FIG. 174

Connections of B T-H (Type OJ) hand-operated, ironclad, draw-out, oil switches

These switches have been developed especially for mining and industrial service. The switch mechanism, instruments (when fitted) and automatic devices are mounted on a sliding carriage, connections to the bus-bars and cables being made by plug contacts—*see* Fig 241 (p 192)

Typical combinations of switches and automatic devices are shown above In these diagrams *Y*, *U* represent, respectively, the upper and lower plug sockets in the pedestal, the former being connected to the bus-bars (or incoming cable) and the latter to the outgoing cable. The corresponding plugs, which are fitted to the carriage, are represented by *X* and *W*

In Fig 172 the switch is provided with series trip coils, *T*, no-volt release, *N*; an ammeter and a voltmeter.[1]

Fig 173 shows the arrangement adopted for high-voltage circuits In this case the no-volt release coil and voltmeter are supplied from a potential transformer *P*, which is mounted in a separate chamber (*see* Fig. 242, p 193), connections between the secondary winding and switch carriage being made by means of plugs and sockets, *Z*

Fig 174 shows the connections of a switch with leakage protective relay and special core-balancing current transformer, *C* (*see* p 132 for particulars).

[1] Alternatively, the voltmeter may be mounted on the connection chamber, in which case potential plugs and sockets (*Z*, Fig. 173) are required

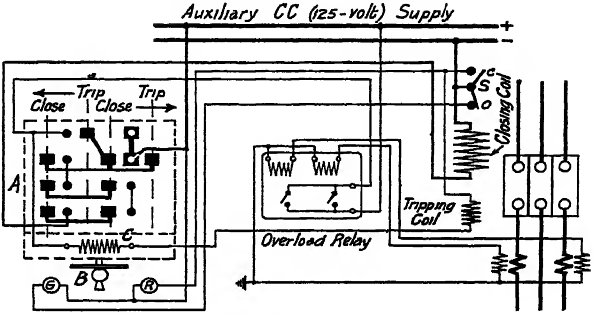


FIG 175 — Connections of Metropolitan-Vickers solenoid-operated oil switch and controller

The controller is arranged on the "free-handle" principle, a clutch being inserted between the drum, A, carrying the segments, and the operating handle, B The drum is provided with a spring return from the "close" position Normally, A and B are mechanically connected by the clutch , but when the tripping coil of the switch is energized, a de-clutching coil C, is excited, which breaks the mechanical connection between A and B Thus the oil switch cannot be held closed on a short-circuit The auxiliary switch, S, which controls the red (R) and green (G) indicating lamps on the switch board, is operated by the mechanism of the oil switch

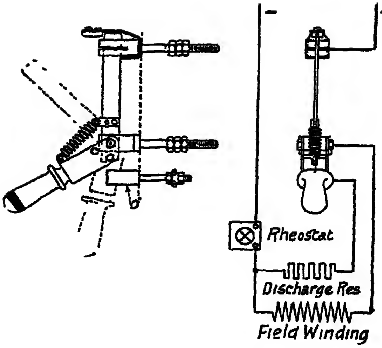


FIG 176.—Connections of single-pole field discharge switch.

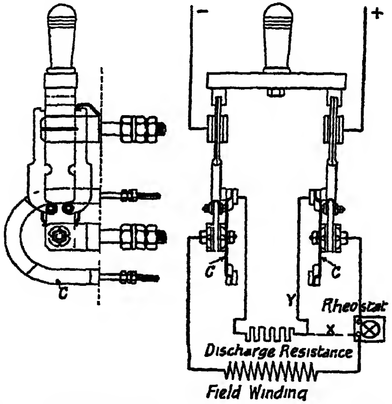


FIG 177 —Connections of a double-pole field discharge switch

The diagram refers to a double-throw switch, the lower main contacts being omitted For a single-throw switch the connection *X* (shown dotted) would be substituted for the connection *Y*, and the right-hand discharge contact *C* would be omitted

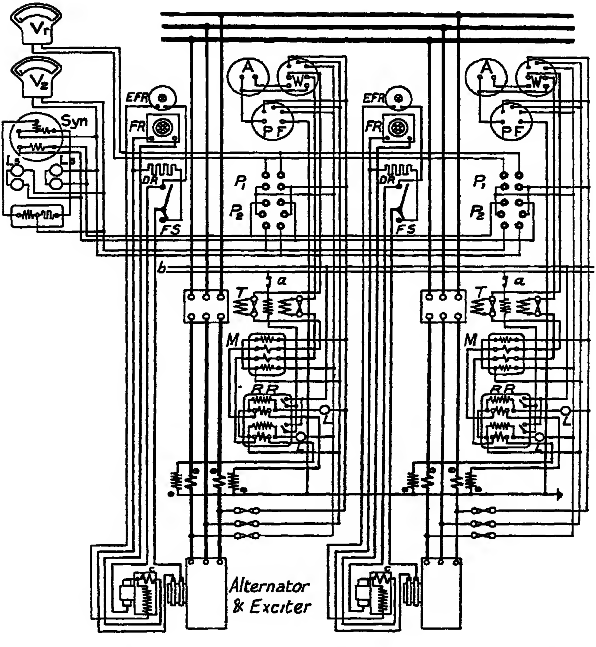


FIG 178 —Connections of switch panels for three-phase, low-voltage, alternators—insulated neutral

The instruments on each panel include—an ammeter, a polyphase wattmeter, a power-factor indicator, a polyphase watt-hour meter (M) and a D P circuit closing reverse-power relay (RR)

The oil switches are provided with two series (overload) trip coils, with time limit fuses, and a shunt-trip coil, with auxiliary switch a, which is energized from a special tripping circuit b

The 4 point receptacles P_1 enable the voltmeter V_1 to be connected to the machine on load, while the 6 point receptacles P_2 are for synchronizing purposes (*see* Fig 153 for connections of plug contacts)

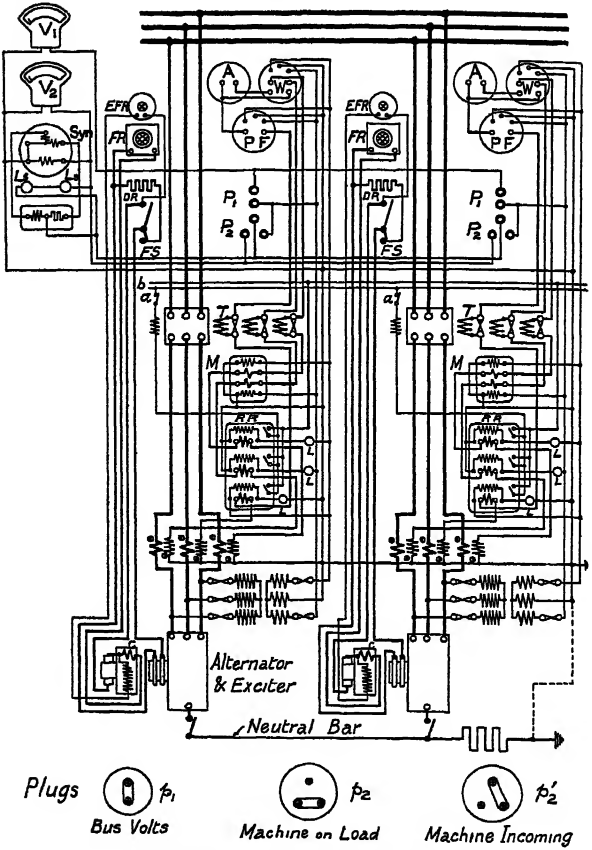


FIG 179 —Connections of switch panels for three-phase, high voltage alternators—earthed neutral (*See* p 143 for references)

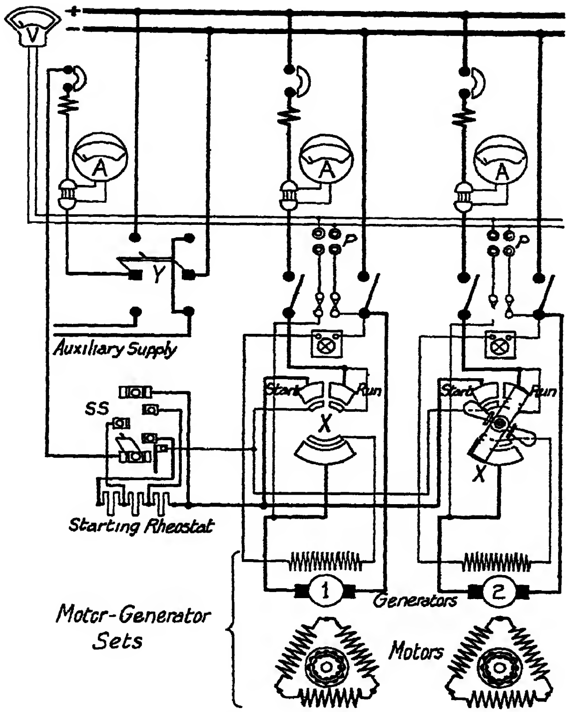


FIG 180—Connections of D C panels for induction motor-generator sets (arranged for starting from D C side)

A common starting panel is provided and each set can be started from either the bus bars or an auxiliary supply At starting, switch Y is placed in the "starting" position, the main negative switch is closed and the set is started by closing the circuit breaker and switches Y, SS, on the starting panel the speed being adjusted to the synchronous speed of induction motor by means of the field rheostat After the induction motor has been switched in, the D C machine is disconnected from the starting panel and connected to the bus-bars

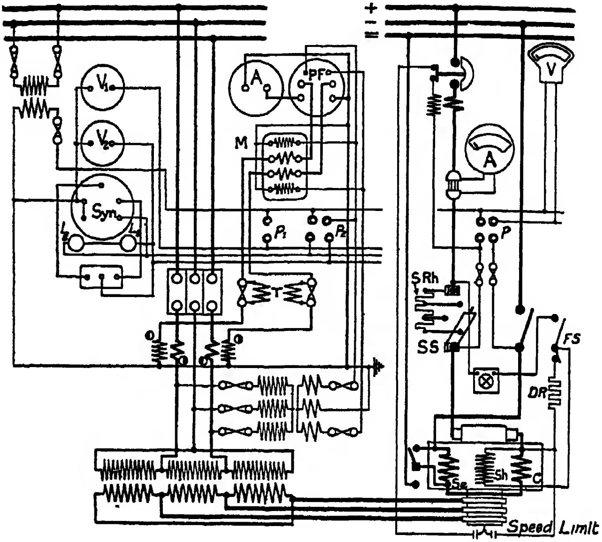


FIG 181.—Connections of switch panels for three-phase rotary converter started from D C side

The machine is started from the D C bus-bars by means of a multi-contact starting switch (*SS*) and rheostat (*SRh*), the circuit breaker, negative main switch and field switch being closed, and the equalizer being in the upper position (which short-circuits the series field winding)

The machine is synchronized on the high-tension side of the transformers

P, 4-point plug receptacle for D C volts,

P_1 2-point plug receptacle for A C bus volts,

P_2, 4-point plug receptacle for synchronizing

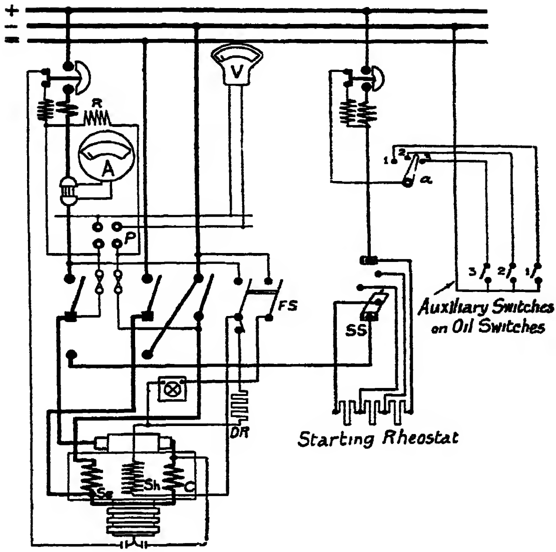


FIG 182 —Connections of D C switch panels for rotary converter started from D C side using common starting panel for a number of machines

The positive and equalizer switches are double throw At starting these switches are thrown to lower position, thus connecting the machine to the bus-bars *via* the starting panel and cutting out the series field winding

The machine is synchronized on the high-tension side of transformers when the oil switch closes, the circuit breaker on the starting panel is tripped automatically by the closing of an auxiliary switch on the oil switch mechanism The positive and equalizer switches are then opened and the machine is connected to the D C bus-bars

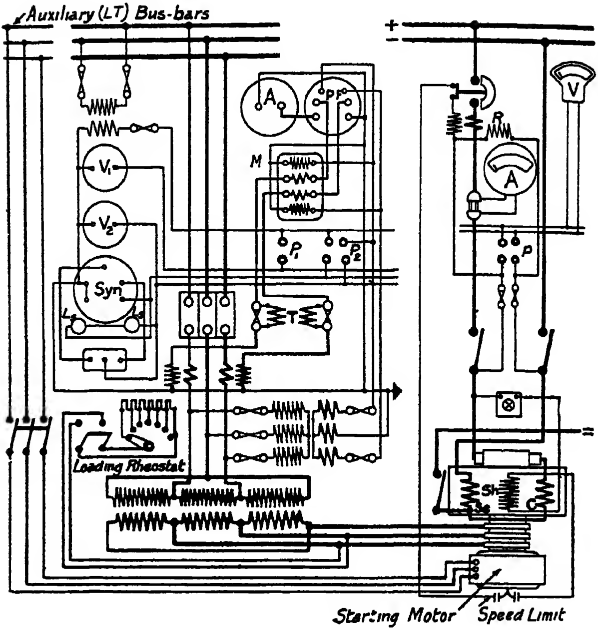


FIG 183 —Connections of switch panels for three-phase rotary converter started from A C side by induction motor

The machine is synchronized on the high-tension side of the transformers, exact adjustment of the speed of the starting motor being obtained by loading one phase of the armature (of rotary converter) on a rheostat

[NOTE —The induction motor has a high-resistance squirrel-cage rotor and the number of poles is a pair less than the number on the rotary converter]

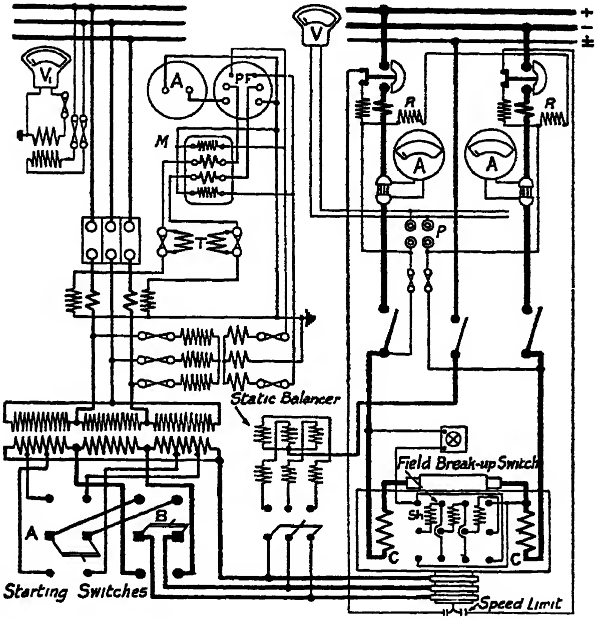


FIG 184—Connections of switch panels for three-phase self-synchronizing rotary converter—supplying three-wire D C system—started from A C side

Two tappings are provided on the secondary windings of two transformers and these tappings are connected to two D P, D T switches *A*, *B* The sequence of starting operations is as follows—

Open field-break-up switch and switches on D C panel Close oil switch Throw switches *A* and *B* " up " [This connects the low-voltage tappings to slip rings] Throw switch *A* " down " [This connects the intermediate tappings to slip rings] Close field-break-up switch and if polarity is correct[1] throw switch *B* " down " Connect machine to D C bus-bars

[1] If polarity is not correct the armature will have to be "slipped a pole" by reversing the field

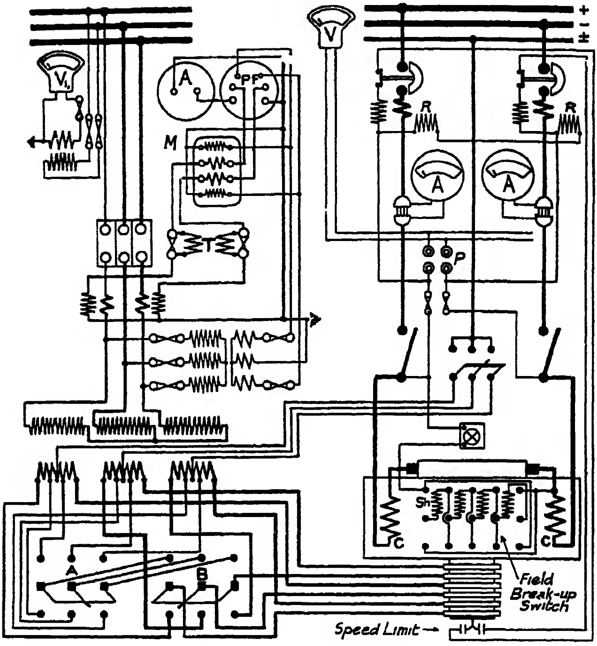


Fig 185 —Connections of switch panels for six-phase self-synchronizing rotary converter supplying three-wire D C system

The machine is started on the A C side at reduced voltage

The sequence of starting operations is the same as that for the three-phase machine of Fig 184.

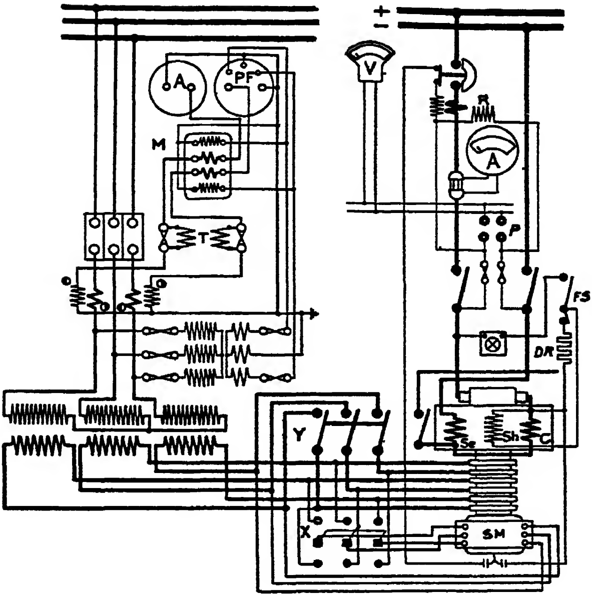


FIG 186 —Connections of switch panels for six-phase self-synchronizing (induction motor started) rotary converter

The machine is started by an induction motor (*SM*), which is first connected directly to the transformers and then connected in series with the transformers and slip rings to enable the converter to synchronize.

The sequence of starting operations is as follows—

Open all switches on D C panel Close oil switch Throw switch *X* "up," switch *Y* being open When machine has run up to speed, throw switch *X* down and close field switch (*FS*) If field rheostat has been properly adjusted the machine will pull into synchronism When this occurs close switch *Y*, open switch *X* and connect machine to D C bus-bars

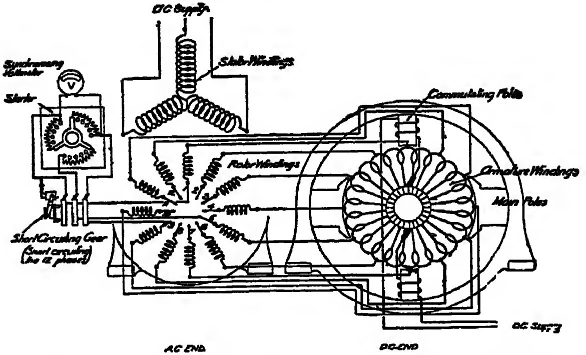


FIG. 187—Diagram of circuits of motor-converter.

The motor-converter consists of an induction machine and a D.C. machine rigidly coupled together (*see* Figs 256, 257), the rotor windings of both machines being interconnected, as indicated in Fig 187. The induction machine performs the functions of an induction motor and a transformer, while the D.C. machine performs the functions of a generator (the mechanical energy being supplied by the induction motor) and a rotary converter (the electrical energy being supplied from the rotor winding of induction machine). Due to the cascade connection of the machines the speed of the set will be given—in r p m—by

$$\frac{120 \times \text{frequency of supply}}{\text{sum of numbers of poles on both machines}}$$

The rotor winding is usually wound for twelve phases, of which three (on large machines, six) are connected to slip-rings for starting purposes. The slip rings, together with the free ends of the rotor winding, are connected to a short-circuiting device which, when closed, forms the neutral point of the rotor winding

The set is started from the A C side by exciting the stator winding and closing the rotor circuit through a non-inductive starting rheostat, the field winding of D C machine being self-excited and closed A portion of the rheostat is cut out to bring the speed up to synchronism and the short-circuiting device is operated at synchronous speed—indicated by the voltmeter pointer remaining stationary near zero [NOTE—While the set is running up to speed and the D C. machine is building-up, the voltmeter pointer oscillates over a portion of the scale. As the speed approaches synchronism the oscillations become slower and at synchronous speed the pointer remains at rest near zero]

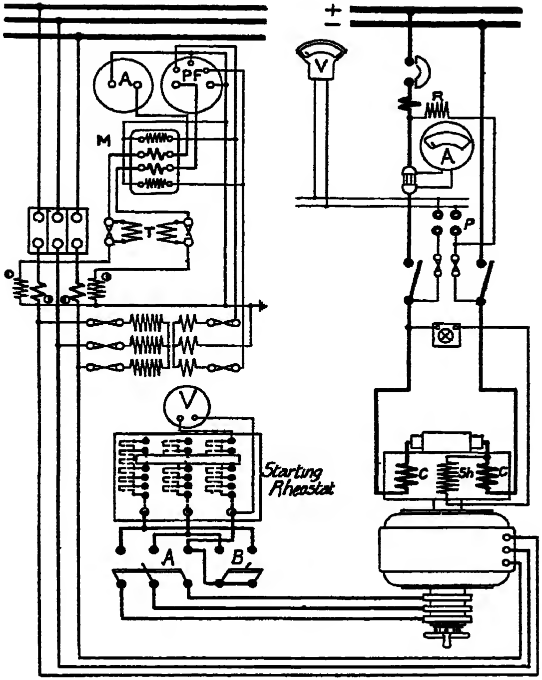


FIG 188—Connections of switch panels for Peebles motor-converter [Bruce Peebles & Co]

The set is started from the A C side, the sequence of operations being as follows—

Close oil switch and switch *A* When voltmeter, *V*, indicates synchronism close switch *B* and short-circuit slip rings

The starting rheostat is permanently adjusted so that the set will reach synchronous speed when the field rheostat is in the normal position. Adjustment of speed (if required) for synchronizing may be obtained by adjusting the field rheostat

Fig 257 (p 204) shows a group of machines with starters The left-hand and right-hand switches on the starters correspond, respectively, to switches *A* and *B* above

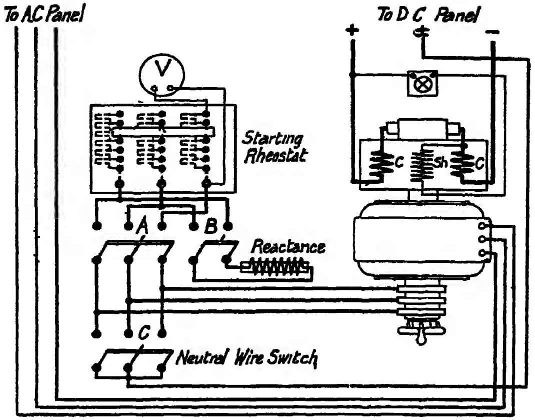


Fig 189 —Connections of starting switches and rheostat for Peebles three-wire, self-synchronizing motor-converter

The starting rheostat consists of a *fixed* non-inductive resistance (as shown in Fig 188) As the speed of the set approaches synchronism a choking coil is connected across two of the slip rings, which enables the machine to lock into synchronism automatically

The starting operations are as follows—Close oil switch and switch *A* When machine has run up to speed, close switch *B* Short-circuit the slip rings as soon as the machine locks into synchronism Finally close switch *C* and open switches *A*, *B*

Note —The self-synchronizing feature of the motor converter has been developed by Messrs Bruce Peebles & Co and results in the starting operations for these machines being exceedingly simple

Thus, as far as starting and operation are concerned, the self-synchronizing motor-converter is the simplest of all classes of converting machinery.

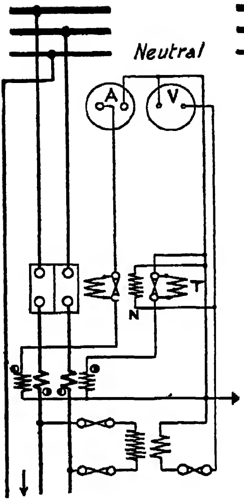


FIG. 190

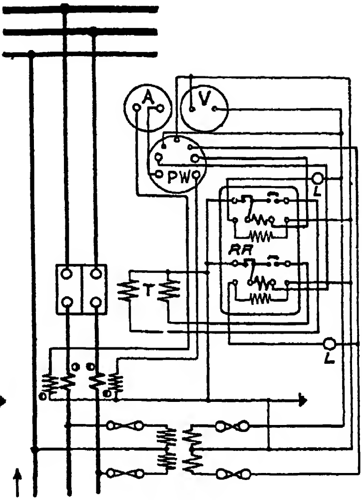


FIG 191

Connections of feeder panels for two-phase three-wire circuits Fig 190, outgoing feeder Fig 191, incoming feeder

Note to Figs 190–197 —The protective devices on the outgoing feeder panels consist of time-limit overload trip coils, *T*, and a low voltage release, *N* The panels for the three-phase circuits with earthed neutral are equipped with leakage protective trip coils—connected in accordance with Fig 163, p 132—in addition to overload trip coils and a low-voltage release

The protective apparatus on the incoming feeder panels consists of a circuit-opening reverse power relay *RR*

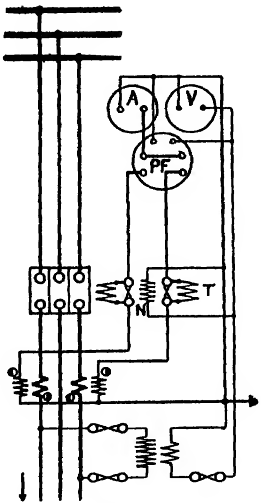


FIG 192

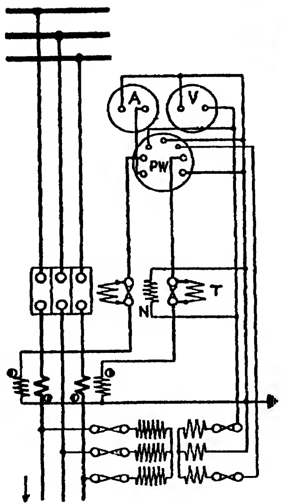


FIG 193

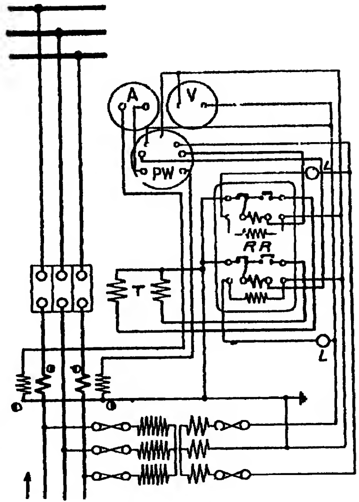


FIG. 194

Connections of feeder panels for three-phase circuits with insulated neutral Figs. 192, 193, outgoing feeders Fig 194, incoming feeder

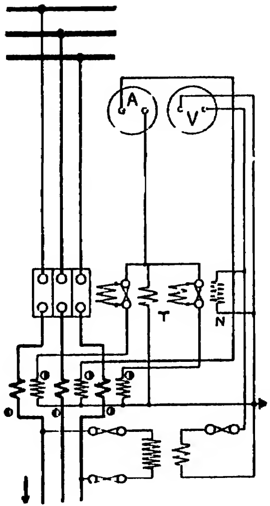


FIG 195

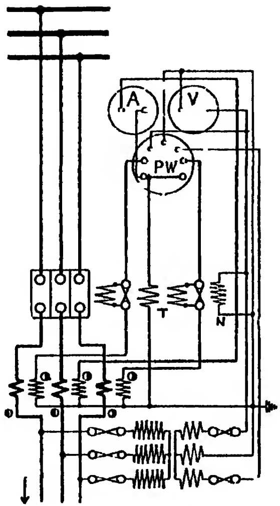


FIG. 196.

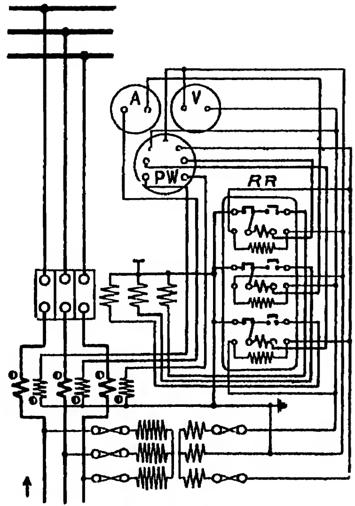


FIG 197

Connections of feeder panels for three-phase circuits with earthed neutral. Figs. 195, 196, outgoing feeders, Fig 197, incoming feeder

SECTION 9

Automatic Voltage Regulators

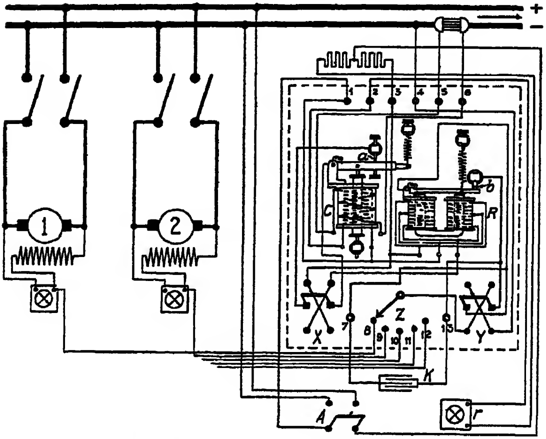


FIG 198 —Connections of B T -H. Tirrill regulator (Type TD, Form GG) for small D C generators The rheostat *r* is provided for the purpose of adjusting the bus-bar voltage [*See* p 158 for illustration of regulator.]

Tirrill regulators are of the vibrating contact type and operate by rapidly short-circuiting and cutting-in the field rheostat of generator (or exciter, in the case of separately-excited machines)

The **essential parts of a Tirrill regulator** are (1) a differential relay, with laminated magnetic circuit and contacts suitable for opening and closing a shunt circuit across the field rheostat, (2) a control relay, for operating the differential relay.

The **differential relay** (*R*, Figs 198, 200) has a pivoted armature, the free end of which carries a contact, which, when the relay core is demagnetized, is held up against a fixed contact by means of a spring These contacts (*b*, Figs 198, 200) are connected to the terminals of the field rheostat *via* a cut-out switch (*Z*, Fig 198) and a reversing switch, *Y*, by means of which the direction of current through the contacts can be reversed, thus producing uniform wear on both contacts A condenser, *K*, is connected in parallel with the contacts *b* for

the purpose of preventing arcing. One winding of the relay is excited directly from the D C. bus-bars (or exciter) and the other winding is excited from the same source of supply through the contacts, *a*, of the control relay

The **control relay of the D.C. regulator** consists of a solenoid *C*, having an adjustable core (at bottom) and a movable plunger which is attached to a pivoted lever carrying one of the contacts *a*, the free end of the lever being supported by a spring which tends to keep the contacts *a* closed. The solenoid is excited from the bus-bars and is so adjusted that at normal voltage the pull on plunger just balances the upward pull due to the spring. When the voltage is below normal, contacts *a* are closed and the core of differential relay (*R*) is demagnetized: contacts *b* are, therefore, closed and the field rheostat is shunted When the voltage is above normal, contacts *a* are open and the core of relay is magnetized, thus opening contacts *b* and cutting-in the field rheostat, which must be set to maintain, without regulator, a voltage about 40 per cent below normal Under normal conditions the contacts *a*, *b* are in rapid vibration, the time of vibration varying with the load and depending on the point of the magnetization curve at which the generator is working

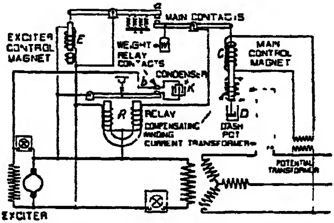


FIG 199 —Schematic diagram of connections of Tirrill A C regulator.

If compounding of the bus-bar voltage is required the solenoid *C*, carries a second winding, which is excited from a shunt inserted in one of the bus-bars between the generators and feeder panels, as shown in Fig 198 This winding is connected in opposition to the main winding With large D C generators the field is separately excited from an exciter set, and the regulator operates on the field circuit of the exciter In this case the regulator is similar to that illustrated in Fig 252.

The **control relay of the A.C. regulator** consists of two solenoids and a double system of pivoted levers which carry the contacts controlling the differential relay One solenoid, *E* (Figs 199, 200) is excited from the exciter circuit, while the other, *C*, is excited from a potential transformer connected across the bus-bars This solenoid (*C*) may also be wound with a differential winding, which is excited from a current transformer in the main circuit as shown in Fig 199 The solenoid *C* is so designed and adjusted that, for constant voltage, the pull is independent of the position of the plunger A weight *W* is, therefore, used on the lever to maintain equilibrium

With constant bus-bar voltage the position of equilibrium

of this lever will vary with the circuit conditions, and, as the movements of the lever are damped by a dashpot *D*, the lower of the main contacts *a* may be considered as stationary so long as the circuit conditions remain constant The exciter solenoid, *E*, will then regulate the exciter for constant voltage in the manner described above

Should the circuit conditions change, the position of equilibrium of the main control lever (when normal voltage has been restored) will be altered, and the exciter will be regulated to give a voltage corresponding to the excitation required on the alternator

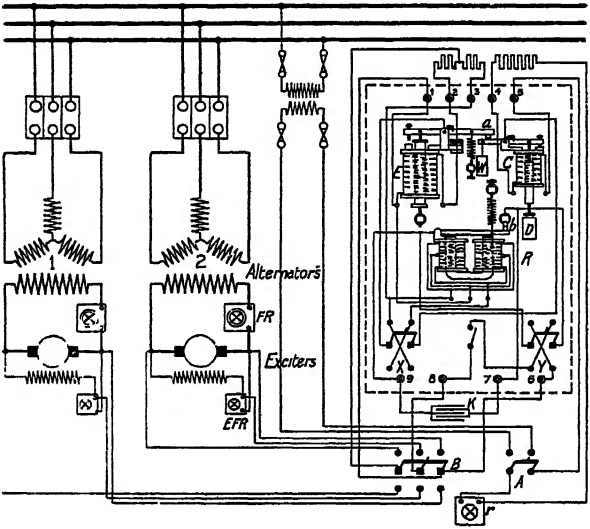


Fig 200 —Connections of B T-H Tirrill regulator (Type TA, Form AA2) for A C generators The rheostat *r* is provided for the purpose of adjusting the bus-bars voltage The switch *A* cuts out the control solenoid, *C*, and the switch *B* connects the regulator to the exciter of the machine to be regulated

Brown-Boveri voltage regulators consist of a spring-controlled motor, operated by the voltage of the circuit to be regulated. The armature of motor is lightly pivoted and transmits its movements to two or more contact sectors which roll over the contacts of a special rheostat in the field circuit of generator (or exciter), thereby adjusting the excitation to the required value.

The **driving system of the D.C. regulator** (Figs 201, 202) consists of an armature with a single coil, *h*, which moves in the field produced by an electro-magnet, the coil (*h*) and exciting winding (*i*) of electro-magnet being connected in series across the bus-bars. Compounding of the bus-bar voltage is obtained by a winding, *I* (opposing the exciting winding *i*), which is connected to a shunt inserted in one of the bus-bars (*see* Fig. 205), an adjustable resistance, *u*, being connected in parallel with this winding for the purpose of adjusting the compounding

The torque exerted by the armature is dependent upon the bus-bar voltage, and the movement of the armature is opposed by a spring, *f*, the tension of which can be adjusted by a worm and worm-wheel, *r*, by which means the regulator can be set to a definite bus-bar voltage In order to obtain an astatic condition over the whole range of movement of the armature the strength of the magnetic field and the torque are arranged to increase in the same proportion.

The contact sectors, *s*, are centred in jewelled bearings mounted on springs, *d*, which are carried on the armature spindle The sectors (and contacts, *k*) are arranged radially relative to the armature so that the spring pressures neutralize each other, thus rendering the whole system practically frictionless

The **damping system** consists of an aluminium disc, *o*, which is driven from the armature spindle by a toothed sector, *p*, and which rotates between the poles of two permanent magnets, *m* The sector, *p*, is flexibly connected to the armature spindle by a sleeve and spring coupling, *q* This arrangement provides a small time lag between the movement of the armature and that of the damping system, so that, at the moment a change of voltage occurs, the damping device is inoperative and the armature carries the contact sectors momentarily past the actual position which they should occupy. The movement, however, is quickly followed by a movement of the damping disc and the contact sectors are brought back to their final position without oscillation

The armature and moving system may be locked by mechanically connecting a pointer *z*, attached to the armature, to a projection, *y*, carried on the contact arm *i*.

The **driving system of the A.C.** regulator (Figs 203, 204) consists of a light aluminium drum, *c*, which is pivoted between the poles of an electro-magnet, *e*, the windings of which are arranged to produce a rotating field The torque is balanced by a compensated spring system so that the resultant opposing torque is constant for all positions of the armature.

NOTE —The maximum voltage variation of a circuit controlled by an automatic voltage regulator is generally less than 1 per cent of normal voltage under any conditions of load

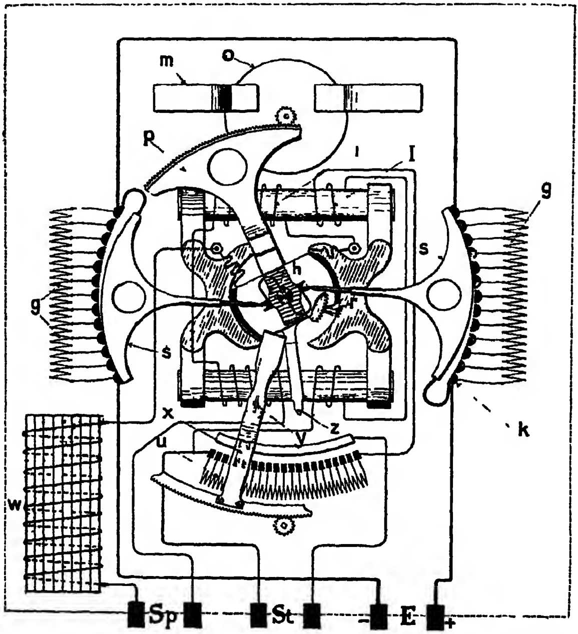


FIG 201 —Internal connections of Brown-Boveri voltage regulator for D C. circuits

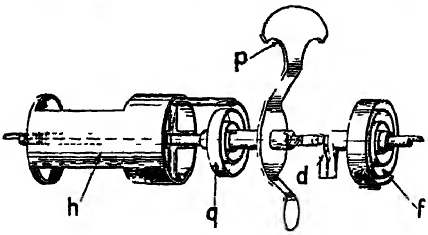


FIG 202 — Moving system of D C regulator

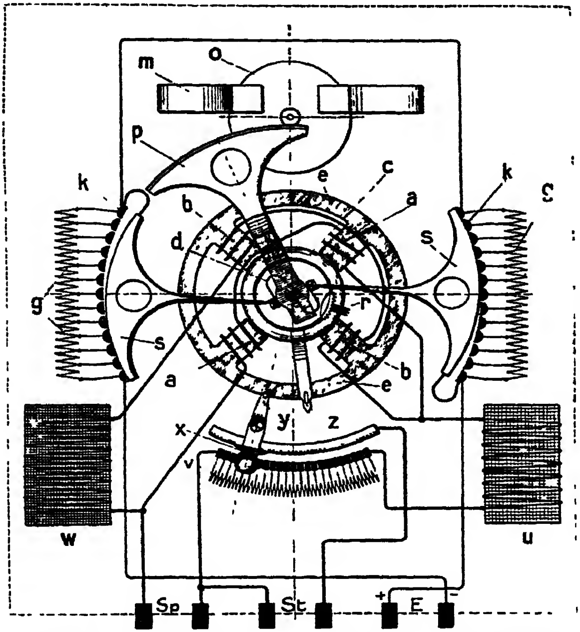


FIG 203 —Internal connections of Brown-Boveri voltage regulator for A C circuits

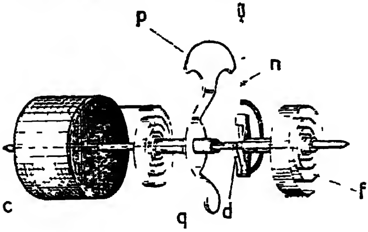


FIG 204 —Moving system of A C regulator

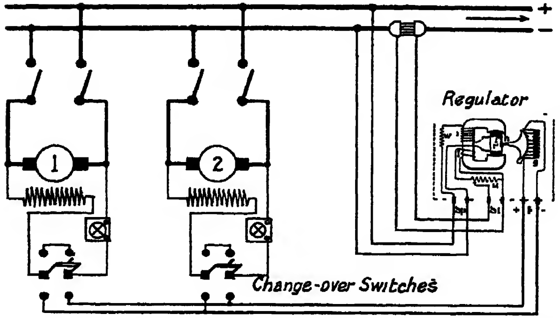


FIG 205 —Circuit connections of Brown-Boveri D C regulator.

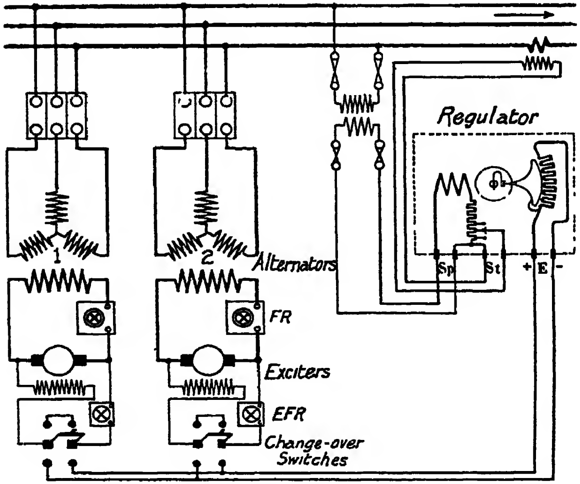


FIG 206 —Circuit connections of Brown-Boveri A C. regulator

APPENDIX I

Tables, Curves and Data relating to Control Apparatus

Curves of full-load currents for D.C and A.C. motors —Particulars of cables—Overload ratings of D.C and A C motors and generators—Fuse wires for porcelain-handle fusible cut-outs—Service ratings of starting rheostats for D C and A C motors—Starting current and torque for three-phase induction motors with squirrel-cage rotors—Ratings of trip coils for oil switches—Volt-amperes required by A C. switchboard instruments—Characteristic curves for time limit overload relays, dash-pots and fuses

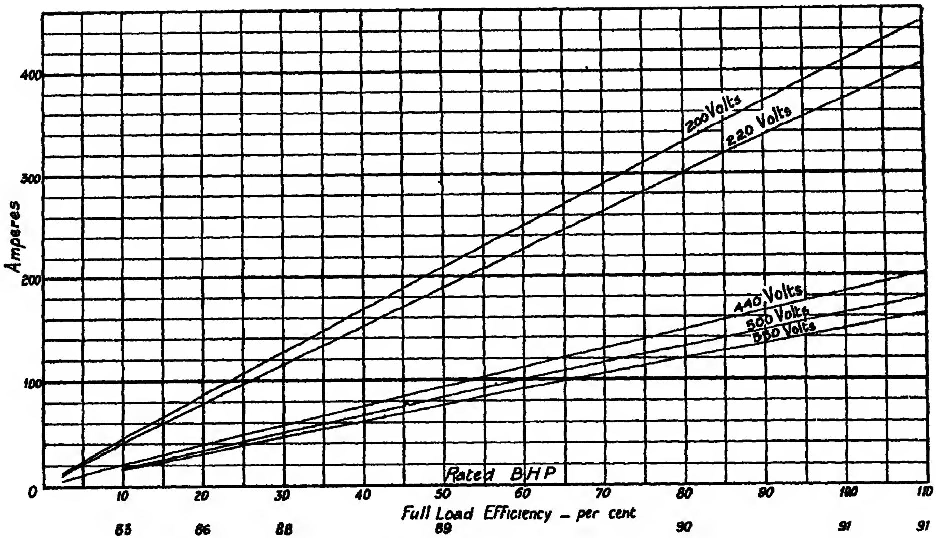


FIG 207 —Curves of approximate full-load currents of direct-current motors

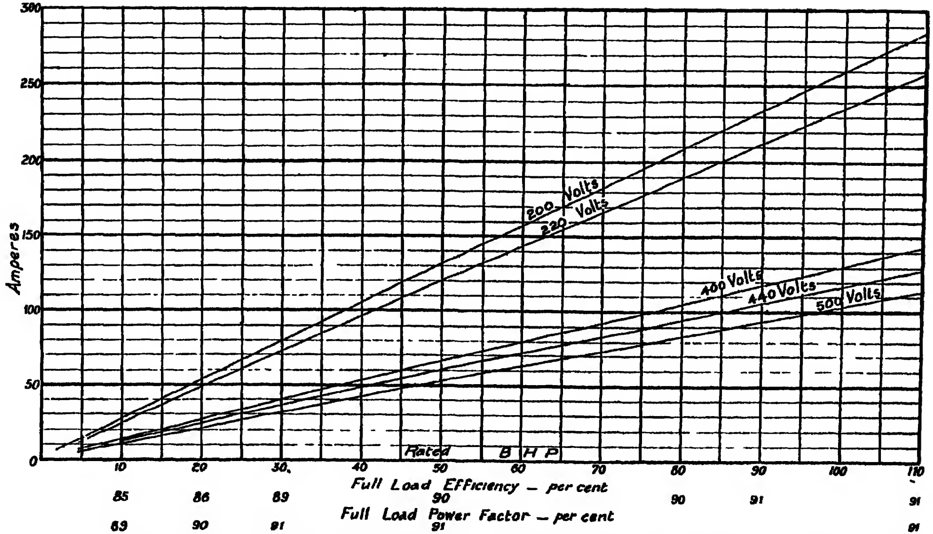


FIG 208 —Curves of approximate full-load (line) currents of three-phase induction motors

NOTE —For two-phase motors the full load currents are, approximately, 10 per cent less than the above values, and for single-phase induction motors the full-load currents are, approximately, double the above values

TABLE

PARTICULARS OF CABLES

Number of Wires and Diameter of each Wire (In)	Nominal cross-sectional area of Cable.	Resistance per 1000 yards at 60° F	Maximum permissible Current [1]		Voltage drop per 100 ft of cable when carrying maximum permissible current	
			Rubber-insulated Cables	Paper-insulated Cables.	Rubber-insulated Cables (100° F.).	Paper-insulated Cables (130° F)
	Sq In	Ohms	Amp	Amp	Volts	Volts
1/ 044	0·0015	15 79	6 1	—	3·5	—
1/ 064	0 003	7·46	12 9	—	3 5	—
7/ 044	0 0125	2 29	31	42	2 6	3 7
7/ 052	0 017	1 64	37	57	2 2	3 6
7/·064	0 022	1 08	46	75	1 8	3·12
19/·052	0 04	0 606	64	104	1 4	2 43
19/·064	0 06	0 4	83	135	1 22	2 08
19/ 072	0 075	0 316	97	157	1 12	1 92
19/ 083	0 1	0 238	118	191	1 02	1 75
37/ 064	0 12	0 205	130	210	0·98	1 66
37/·072	0 15	0 162	152	246	0 9	1 55
37/ 083	0 2	0 122	184	296	0 82	1·4
37/ 093	0 25	0 097	214	343	0 75	1 3
37/ 103	0 3	0 079	240	385	0·69	1 17
61/ 093	0 4	0 059	288	464	0 62	1 06
61/ 103	0 5	0 048	332	540	0 58	1 0
91/ 093	0·6	0·0396	384	624	0·55	0 95
91/·103	0·75	0 0323	461	738	0 54	0 92
127/ 103	1·0	0 0231	595	932	0 5	0 83

[1] It must not be assumed that this current is always permissible (*see* below) The figures in these columns apply to situations where the temperature of the air does not exceed 80° F (26 7° C) The values given for the maximum permissible current allow for a rise of temperature of 20°F (11 1°C) for rubber-insulated cables, and of 50° F. (27 8° C) for paper-insulated cables. A margin in the maximum possible temperature of the cables has been allowed to provide for contingencies, the limiting temperatures being 120° F. (48 9° C) for rubber-insulated cables and 176° F (80° C) for paper-insulated cables.

[2] Minimum insulation resistance per mile at 60° F —600-2,000 megohms (depending on size of cable). Test pressure—1,000 volts (alternating) for half an hour.

I

[I E.E WIRING RULES]

Minimum Radial Thickness of Dielectric			Minimum Thickness of Lead Sheath.	Approximate Overall Diameter of Complete Rubber-insulated Cable.
Vulcanized Rubber (250-volt-Cables)[a]	Vulcanized Rubber (650 volt Cables)[a]	Paper		
In	In	In	In	In
0 034	0 055	—	—	0·18
0 034	0 057	—	—	0·2
0 043	0 06	0 08	0 06	0·29
0 046	0 061	0 08	0 06	0·32
0.049	0 062	0 08	0·06	0·36
0 056	0 063	0 08	0 06	0·44
0 062	0 065	0 08	0 07	0·51
0 066	0 066	0 08	0 07	0·6
0 072	0 072	0 08	0 07	0 66
0 075	0 075	0 08	0 07	0 7
0 08	0 08	0.08	0 07	0·77
0 088	0 088	0 08	0 07	0·89
0 095	0 095	0 09	0 08	0 97
0 102	0 102	0 09	0 08	1 06
0 114	0 114	0 09	0 09	1 2
0 121	0 121	0 09	0 09	1·3
0 125	0 125	0·1	0 1	1 42
0 131	0 131	0 1	0 1	1 55
0 141	0 141	0 11	0 11	1 77

[a] Minimum insulation resistance per mile at 60° F—2,500–5,000 megohms (depending on size of cable) Test pressure—2,500 volts (alternating) for half an hour

NOTE—The minimum size o cable will be determined as follows—

a For lighting circuits—By the permissible voltage drop, which under ordinary conditions must not exceed 2 per cent, *plus* a constant allowance of 1 volt [No cable smaller than 1 044 is allowed]

b For power circuits.—By the rise in temperature, which must not exceed 20° F (11 1° C) for rubber insulated cables

TABLE II

TEMPERATURE RISE AND OVERLOAD RATING OF MACHINES AND TRANSFORMERS

CLASS	TYPE[1]	Temperature rise [2] Continuous service °C	Temperature rise [2] Continuous service °F	Max permissible observable temperature[3] °C.	Overload rating: Overload (per cent)	Overload rating: Duration
Fractional H P. motors (D.C and A.C)	P TE	40 55	72 90	Field coils[5] 95° Armature[6] 90° Commutator[6] 90°.	25 —	½ hr —
Small self-ventilated motors (with fan) . .	VP, VE PV	40	72		25	½ hr
Medium size D C. Motors and generators without ventilating fans[4] (30–200 H P)	P TE, M	40 50	72 90		25 25	1–2 hrs ½–1 hr
Large D C. machines	O	40	72		25	2 hrs.
Polyphase Induction Motors: 2–25 H P 30–100 H P above 100 H P	P. EV., PV TE, M.	40 50	72 90	Windings[5] 95° Unins'l'd rotor bars[6] 100° Sliprings[6] 90°	25 25 25	½ hr 1 hr 2 hrs
Large A C generators and synchronous motors .	O	40	72	Field coils[5] 95°	10 25	cont 2 hrs.
Transformers—air-cooled	Max permissible temp 95° C (by resistance).					
,, —oil-cooled .	Max. permissible temp of oil 90° C (by thermometer). Max. permissible temp of windings 95° C (by resistance .					

[1] O, open P, protected, TE, totally enclosed, M, mining (flame-proof), VP ventilated protected; E V., enclosed ventilated, P V, pipe ventilated

[2] At sea-level (30" barometer), air temperature not exceeding 25° C (77° F)

[3] For class A insulation (i.e cotton, silk, enamel, paper, etc) For class B insulation (mica, asbestos, etc) the maximum permissible temperature is 20° C higher than that given

[4] Self-ventilated machines (with fans) have the same rating as protected type machines

[5] Temperature to be obtained by resistance measurements

[6] Temperature to be obtained by thermometer.

TABLE III

FUSE WIRES FOR PORCELAIN HANDLE FUSIBLE CUT-OUTS [B T -H Co]

Continuous rating of cut-out.	Gauge of Fuse Wire [1]	No of strands in parallel	Continuous rating of cut-out	Gauge of Fuse Wire [1]	No of strands in parallel
amperes.	S W.G		amperes	S W G	
3	36	1	75	20	4
5	36	2	100	20	6
8	36	3	150	18	5
12	36	6	200	16	5
20	22	1	250	16	6
30	20	1	300	16	7
40	18	1	350	15	6
50	20	2	400	14	6
60	16	1	500	13	6

[1] Tinned copper wire to be used.

The fuses are rated to blow at twice the normal (full-load) current (i e 100 per cent overload) on a time basis of two minutes With a lower rating the fuse would attain an excessive temperature when carrying full-load current When a lower rated fuse is required the cartridge (enclosed) type must be used

TABLE IV

SERVICE RATINGS OF HAND-OPERATED STARTING RHEOSTATS FOR D.C. AND A.C. MOTORS

Rated H P. of Motor.	D C Starting Rheostats.		A C Starting Rheostats
	Duration of Starting Period for "Light duty" Rheostats [1]	Duration of Starting Period for "Heavy-duty" Rheostats [1]	Duration of Starting Period [2]
	Seconds	Seconds	Seconds.
½–1	5	—	—
2	6	—	40
5	7 5	60	40
10	10	60	40
15	12·5	60	40
30	20	60	50
50	30	60	60
75	—	60	60

[1] For starting against full load torque Momentary current peaks during starting not to exceed 150 per cent of full load current

[2] For starting against full load torque

Intervals between successive starts against full-load torque—15 minutes with ventilated resistances; 30 minutes with totally-enclosed resistances.

For services involving frequent starting against full load a drum-type controller with external resistances (or, alternatively, a multiple-switch starter or an auto matic contactor-type starter) must be adopted Resistances for drum-type controllers are usually rated for a two minute starting period and permit of an interval of 45 seconds on the first step of controller

TABLE V

APPROXIMATE VALUES OF STARTING CURRENT (AT FULL VOLTAGE) AND STARTING TORQUE FOR THREE PHASE, 50-CYCLE, INDUCTION MOTORS WITH SQUIRREL-CAGE ROTORS [B T -H Co]

H P of Motor	Average Starting Current	Average Starting Torque
	Per cent of Full-load Current	Per cent of Full-load Torque
½–1	400	125
2–5	500	225
7½–12	500	200
15–20	500	175
25–40	500	150
40–100	550	125
125–150	550	75

TABLE VI

RATINGS OF TRIP COILS FOR OIL SWITCHES

Type of Coil	Rating.	Remarks
Series (direct)	From 5 to 500 amp. Rating of coil is current which it can carry continuously	Rated current of trip coil must correspond to overload (ampere) rating of apparatus controlled by oil switch. Currents in excess of rated current can only be carried momentarily.
Series (for use with transformers)	5 amperes (Standard)	Ratio of current transformer[1] should be so chosen that the full-load current of apparatus controlled by oil switch corresponds to a secondary current of about 3 5 amperes
Shunt	100-650 volts.	Designed for momentary service The circuit of trip coil should be opened either by main contacts of oil switch or by a circuit-opening auxiliary switch operated by the oil switch mechanism
Low-voltage	100-650 volts	Designed for continuous service The low-voltage release is usually designed so that the switch cannot remain in the closed position if the line voltage falls to 50 per cent of normal

[1] Wound for a secondary current of 5 amperes

TABLE VII

VOLT-AMPERES REQUIRED BY A C SWITCHBOARD INSTRUMENTS WHEN USED WITH CURRENT AND POTENTIAL TRANSFORMERS

Type of Instrument.	Volt-amperes corresponding to full-scale deflection
Ammeters[1]—moving-iron (electro-magnetic) type—6" scale	3-5
" — " " " —10"-12" scale	7-10
" —induction type .	10
Voltmeters[2]—moving-iron type—6" scale . .	10-12
" — " " —10"-12" scale	15
" —induction type	10
Wattmeters[3]—dynamometer type { current coils	1-2 (per phase)
{ potential coils	3 (per phase)
Power-factor Indicators[3]—dynamometer type { current coils	1-2 (per phase)
{ potential coils	5 (per phase)
Frequency Indicators[2]—reed type .	6
Synchroscopes[2] .	50
Relays—Overload time limit[1] (induction type)	6
" —Reverse power[3] (differential type) { current coils	12 (per phase)
{ potential coils	30-40 (per phase)

[1] 5-ampere instrument. [2] 110-volt instrument.
[3] 5-ampere current coils 110-volt potential coils

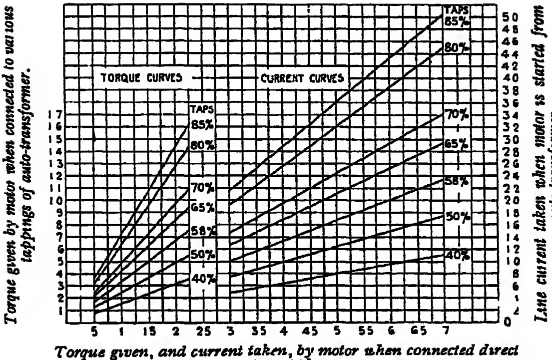


FIG. 209—Curves showing relation between starting current and torque for three-phase induction motors started by auto-transformer. [B T -H. Co]

These curves are used in conjunction with Table V for determining the starting performance of motors with squirrel-cage rotors The ordinates and abscissae are expressed in terms of full-load current and torque.

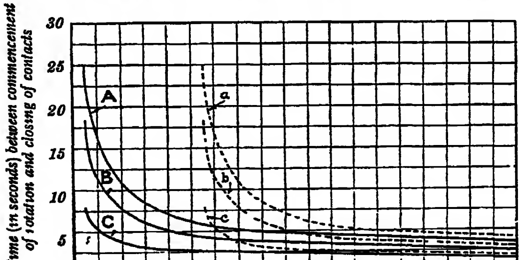


FIG 210—Characteristic curves for Ferranti time limit overload relay (induction type)

Curves *C*, *B*, *A* correspond respectively to time settings of 0, 5, 10 (on instrument scale) and a load setting equivalent to 125 per cent of normal load Curves *c*, *b*, *a* correspond respectively to time settings of 0, 5, 10 and a load setting equivalent to 175 per cent of normal load

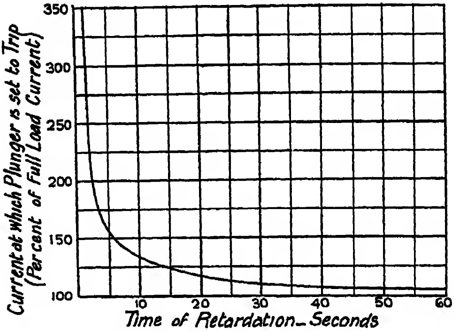


FIG. 211.—Characteristic curve for B T -H time limit dash-pot

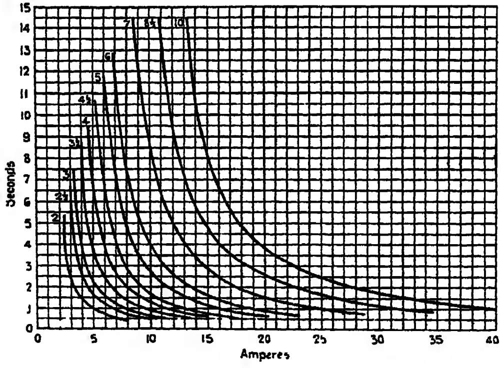


FIG 212 —Characteristic curves for B T -H time limit fuses.

The figures given against the individual curves are the nominal fusing currents of the fuses

NOTE —Fuses rated below 4½ amperes are intended for special trip coils and the current coils of reverse power relays

Fuses rated from 4½ amperes upwards may be used with standard overload trip coils, which may be set to operate at 4 amperes.

APPENDIX II

Illustrations of Control Apparatus

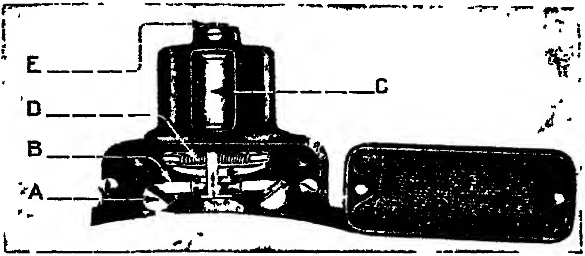


FIG 213 —B T -H safety short-circuiting switch for field rheostats (For connections, *see* Fig 7, p 5)

The switch, *B*, is normally closed by the springs, *D*, assisted by gravity, and, when closed, short circuits the field rheostat The solenoid, *C*, is not sufficiently powerful to open the switch, but will hold it open when it is once raised In order to raise the switch, the contact arm of rheostat must be moved to " all-resistance-out " position, when the arm will engage a trigger and open the switch The solenoid will then hold the switch open, and the speed of the motor may be adjusted by the field rheostat.

The solenoid is connected in series with the field winding and will cease to hold the switch in the open position immediately the field circuit is interrupted Thus, when the motor is re-started, a full field is obtained irrespective of the actual position of the rheostat handwheel This device prevents an adjustable-speed motor being started up on a weak field

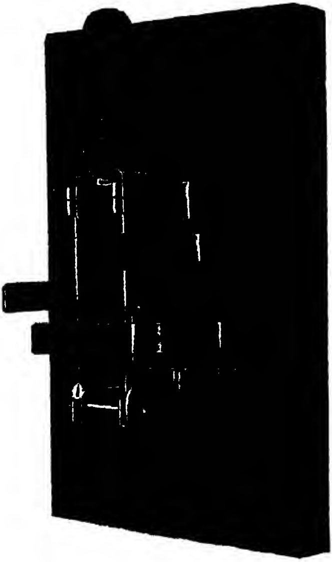


FIG 214.

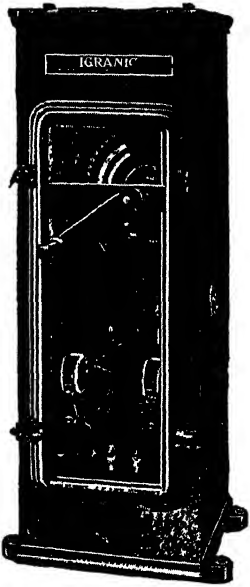


FIG 215

FIG 214—B T-H 4-point starting switch (in closed position).

The resistance contacts are mounted on each side of a double blade, and connect alternately with the outer face of each blade the two blades being connected in parallel in the running position of switch An extra contact, which is clearly shown in the illustration, is provided for the field circuit (For connections, *see* Fig 13, p 11)

FIG 215—Igranic "Conspede" control panel (For description and connections, *see* Fig 9, p 7)

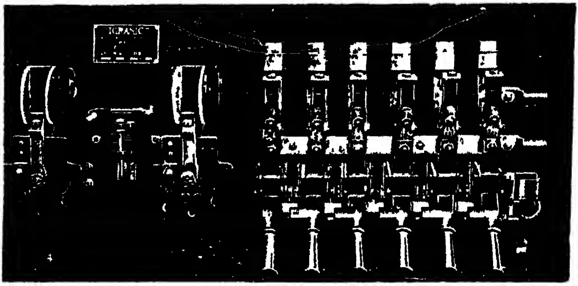


FIG 216.—Igranic multiple-switch starter.

The switches are of the laminated-brush type and are closed by means of a toggle mechanism This operation requires *both* hands and necessitates a hand over-hand movement, as each switch must be held closed until the succeeding switch is closed The last switch is retained in the closed position by means of a no-volt release magnet

FIG 218—Igranic pressure regulator (diaphragm type)

FIG 217.—Igranic, multiple-finger type, self-acting starter The fingers are actuated by a shaft which is operated by a solenoid, the movement being retarded by an air dash-pot (For connections, *see* Fig 16, p 15)

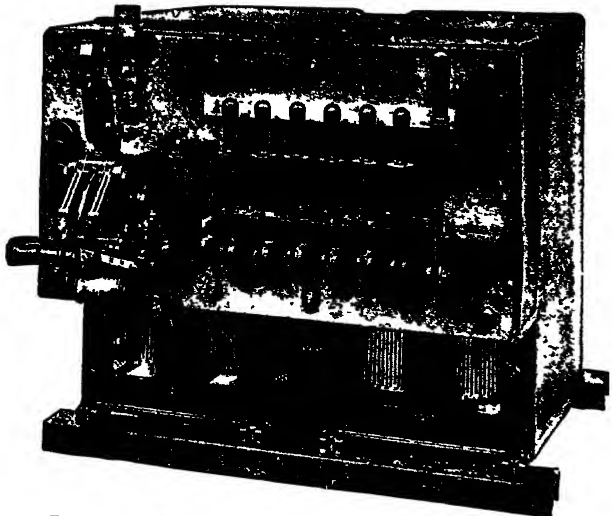


FIG 219 —Multiple-switch starter [General Electric Co]

This illustration shows the interlocking bar between the switches, and the interlocking coil on the circuit breaker. (For connections, *see* Fig 12, p 11.)

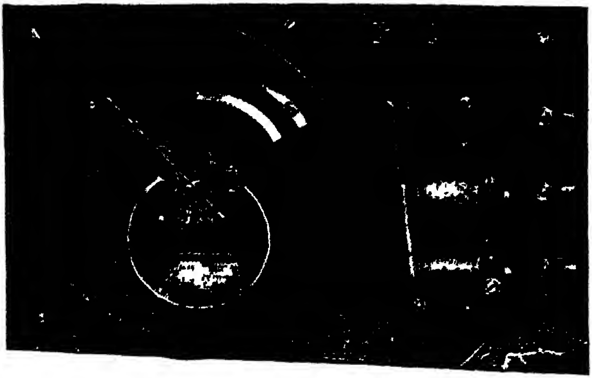


FIG 220 —B T -H Automatic pressure governor with relay (For connections, *see* Fig 110, p 94)

The relay is energized by contacts on the pressure gauge and controls the automatic starting and stopping of the motor The connections are so arranged that the operating circuit of the relay is broken by its own contacts, thus preventing sparking at the gauge contacts The operating coils of the relay are energized momentarily

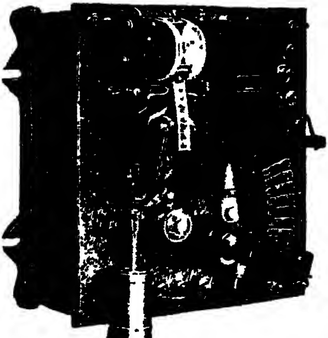


FIG. 221 —Igranic self-acting starter (For connections, *see* Fig 18, p. 16)

The starter consists of a solenoid-operated starting rheostat, the movement of the switch lever being retarded by an oil dashpot, and a contactor for closing and opening the main circuit The contactor is interlocked with the switch lever so that the former cannot close unless the latter is in its lowest position

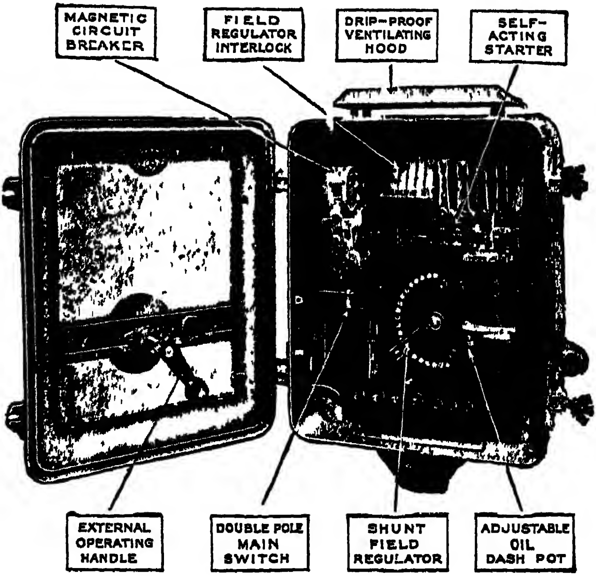


FIG 222.—Igranic Universal Control Panel for electrically-driven printing presses and machine tools (For connections and description, *see* p 17)

The panel is equipped with a D P main switch, a self-acting starter and a field rheostat The D P switch is operated by an external handle, which is interlocked with the cover so that the latter cannot be opened when the switch is closed. The starter is arranged for push-button control.

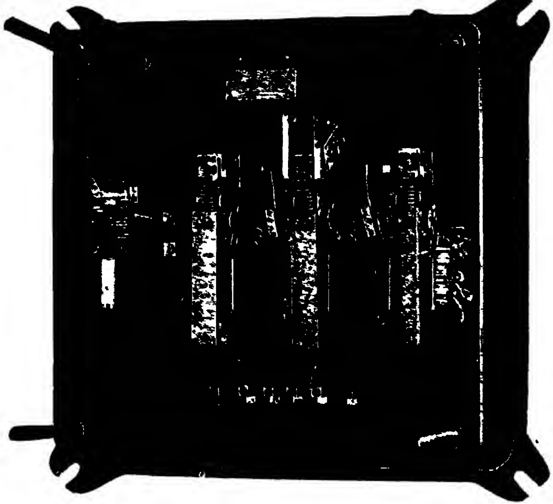


Fig 223.

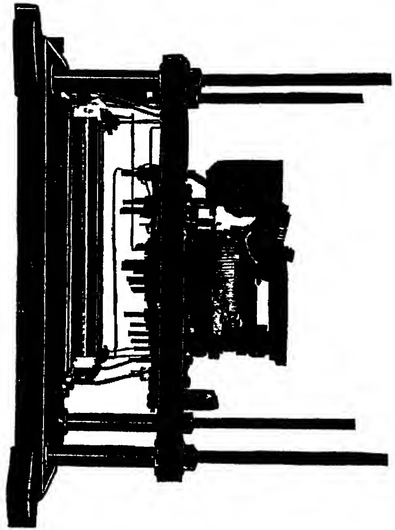


Fig 224

Front and side views of B T -H (Type SMC) automatic starter with series lock-out contactors and overload relay—covers removed. (For connections, *see* Fig 21, p. 20.)

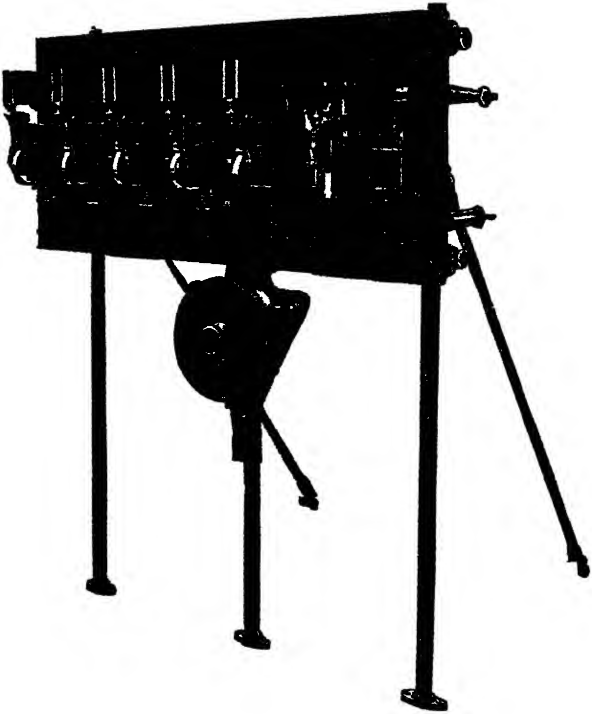


FIG 225 —B T -H. (Type RMC) automatic starter with series-relay type contactors, overload relay, field relay and field rheostat. (For method of operation, *see* pp 25, 26)

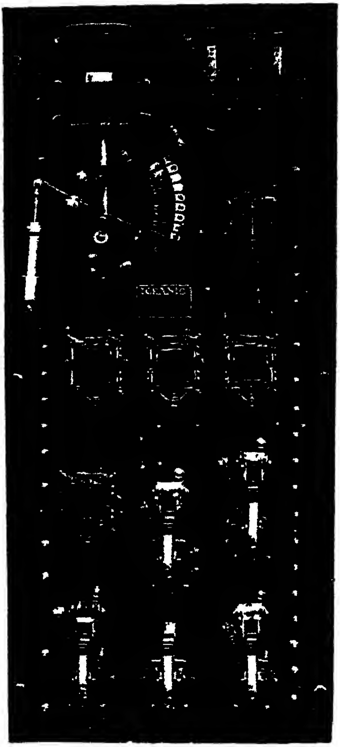


FIG 227 — Top floor limit switch

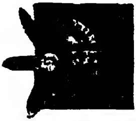


FIG 228 —Inter mediate floor limit switch

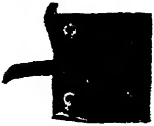


FIG 229 —Bottom floor limit switch

FIG 226 —Igranic control panel for 4-floor push button controlled lift

The connections for a two-floor lift are given in Fig 47, p 40, and the method of working is described on p 41

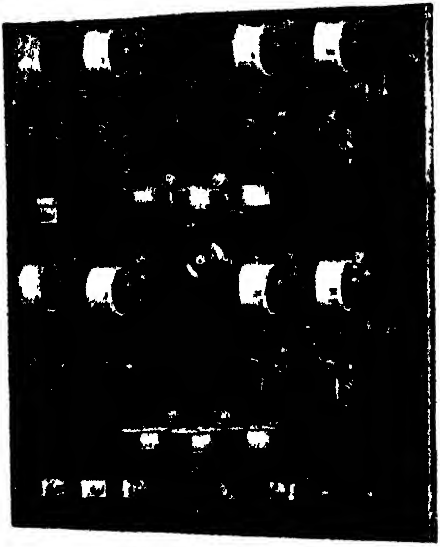


FIG 230 —Igranic automatic starter for single-phase induction motors (For connections, *see* Fig 84, p. 74)

The starter is intended for use with motors in which two windings are provided on the stator—one being a starting winding and the other a main winding it consists of four D P contactors and two series relays, the latter being excited by the rotor currents Two contactors control the stator circuits, while the other two cut out the starting resistance from the rotor circuit under the control of the relays When all the starting resistance has been cut out, the starting winding is automatically disconnected from the supply

FIG 231 —Igranic self-acting starter for single-phase commutator motors. (For connections, *see* Fig. 81, p 72)

The starter consists of three switches which are operated by a crank-shaft, the latter being rotated by means of a rack and pinion when the solenoid is excited The movement of the plunger, to which the rack is attached, is controlled by an air dashpot, the time limit being adjustable

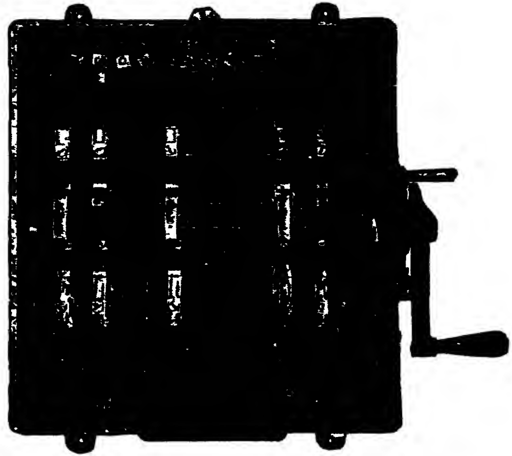


FIG 232 —General Electric Co's auto-transformer starter for three-phase induction motors

The drum-type starting switch is mounted above the auto-transformer (For connections, *see* Fig. 93, p. 80)

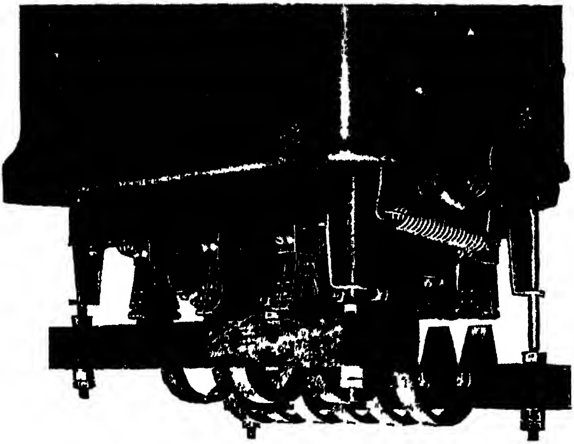


FIG 233—Operating switch of B T -H (Type NR) auto-transformer starter—oil tank removed (For connections, *see* Fig 95, p 81)

The switch is of the double-throw type it consists of two sets of (fixed) contact fingers and two (movable) bars, of insulating material, carrying contacts corresponding to the fingers, the movable contacts being connected to fixed terminals by flexible connections One set of fingers with the corresponding set of contacts, forms the "starting" side of the switch, while the other set forms the "running" side The contact bars have a straight-line motion and are operated from a central shaft, the operating handle having three positions, *viz.*, "off," "starting," "running" An automatic latch prevents the handle being thrown direct from "off" to "running," and a spring returns it to the "off" position from either of the other positions The switch is held in the "running" position by another latch (as shown in Fig 233) which is fitted with a no-volt release.

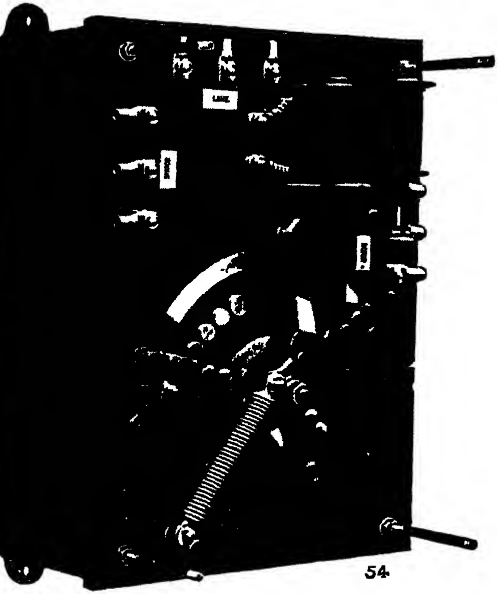


Fig. 234.—Ellison starting rheostat for three-phase induction motors. (For connections, *see* Fig. 99, p. 84.)

The starting switch controls both the stator and rotor circuits: it is provided with a no-volt release, connected across two of the lines, and an overload release connected in either the stator or rotor circuit, the former method being only adopted with motors fitted with slip-ring short-circuiting gear. With the standard method of connection (i.e. overload release coil in rotor circuit) the overload coil is only in circuit in the "running" position of the starting switch.

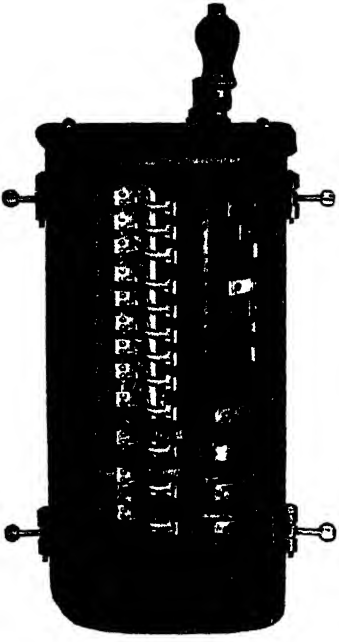


FIG. 235

B T-H (Type T 502) Controller for reversible three-phase induction motor.

The controller cylinder controls both the stator and rotor circuits The connections are given in Fig 101, p. 86.

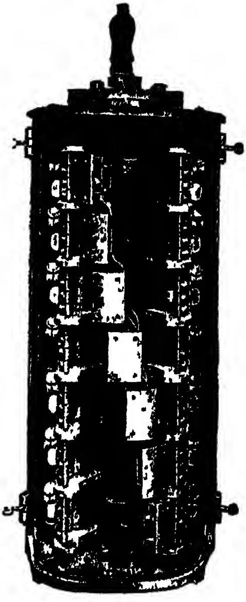


FIG 236

B T-H (Type T 29) Controller for non-reversing three-phase motor

The controller cylinder controls the rotor circuit, the stator circuit being controlled by an oil switch The connections are given in Fig. 103, p. 87.

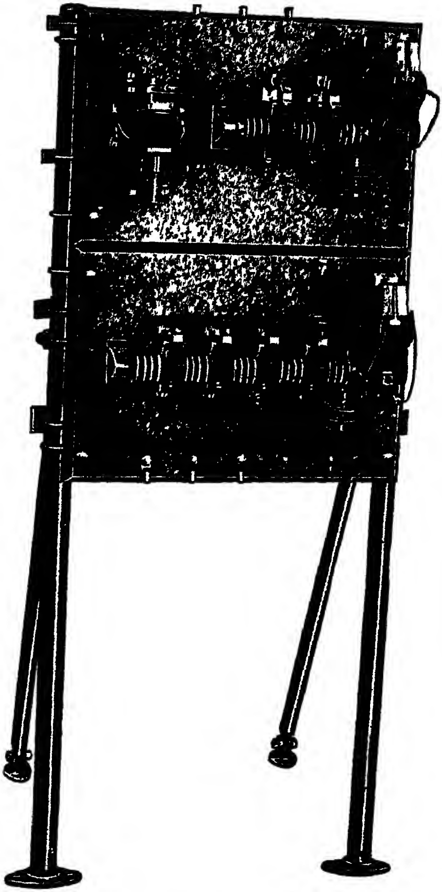


FIG. 237.—B T -H. (Type CR) auto-transformer automatic starting panel for three-phase motors with squirrel-cage rotors. (For connections, *see* Fig. 110, p 94)

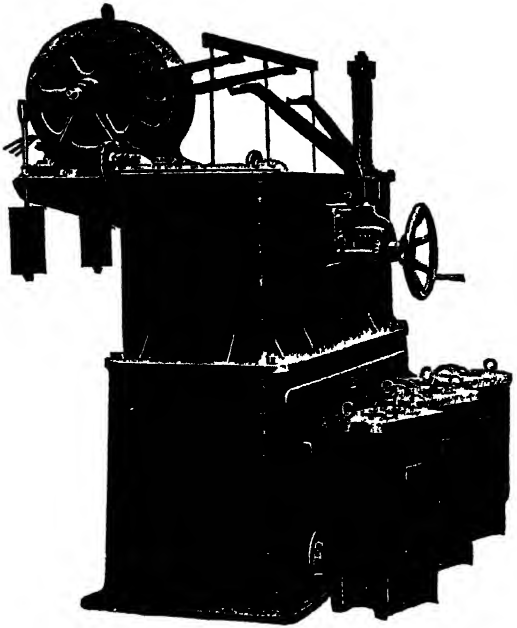


FIG 238.—Metropolitan-Vickers automatic slip regulator for three-phase induction motor (For connections, *see* Fig 113, p 97)

The regulator consists of a water-cooled liquid rheostat, the movable electrodes of which are operated by means of a " motor-magnet "—an induction motor with short-circuited rotor—which is energized from series transformers connected in the circuit of the main motor. The handwheel is provided to enable the regulator to be operated as a starting rheostat.

NOTE.—With the regulator in working order (i e. the electrode chambers and tank full of liquid) and the " motor-magnet " unexcited, the weight of the electrodes and superimposed liquid overbalances the counter weights on the " motor-magnet lever," and the cross-bar rests upon the projecting forks Thus

when the forks are raised to the upper limit of their travel for starting the motor the maximum resistance is inserted in the rotor circuit. For normal working, the forks occupy the position shown in the illustration, and the cross-bar is suspended on the levers of the motor-magnet

FIG 239

FIG 240.

B T.-H. Field circuit breaker, closed and open.

This circuit breaker is designed for the purpose of cutting out, automatically, the field of a faulty alternator immediately after the machine has been disconnected from the bus-bars The breaker is tripped by a shunt tripping coil which is energized by the protective relay —*see* Fig 166, p 134, for connections—and a discharge resistance is connected to the field winding before the main circuit is broken.

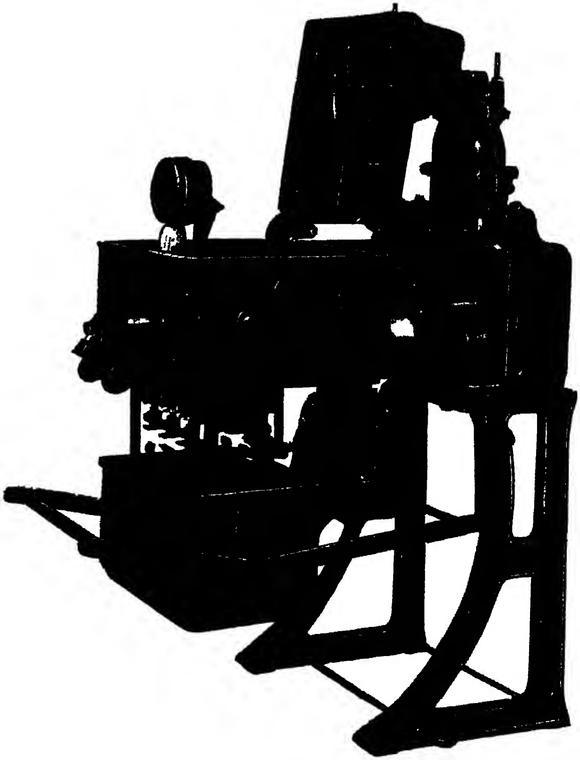


FIG. 241 —B.T.-H. (Type OJ2) " draw-out " oil switch, showing switch body drawn out for inspection, cover open and oil tank lowered

A description of this switch, together with connection diagrams, is given on p. 140

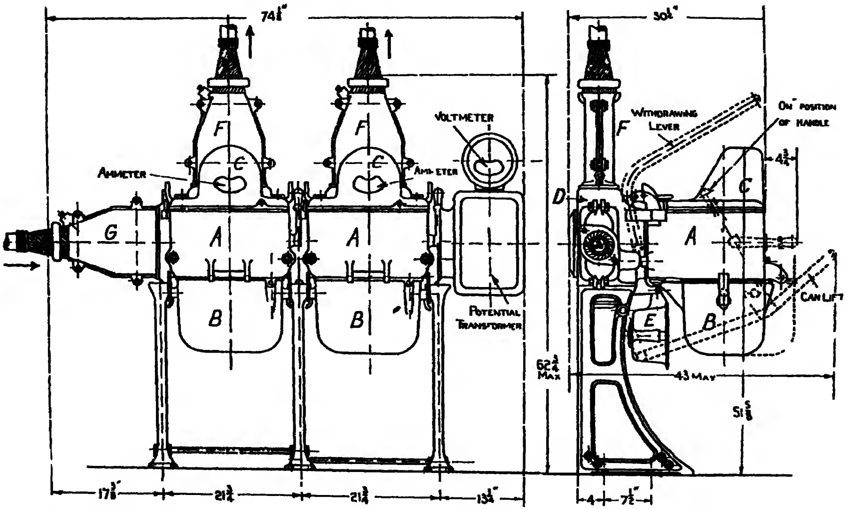


FIG. 242.—Outline drawing of B.T.-H (Type OJ) "draw-out" switchgear. *A*, switch body; *B*, oil tank; *C*, cover; *D*, bus-bar chamber, *E*, cover for connection sockets, *F*, trifurcating cable box for outgoing cable, *G*, trifurcating cable box for incoming cable.

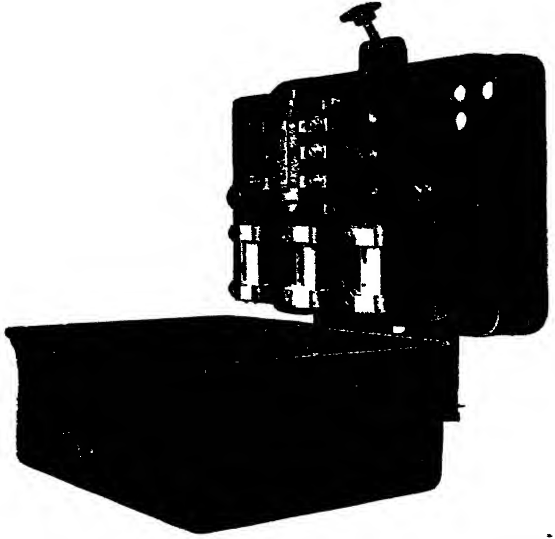


FIG 243—B T-H (Type SH) triple-pole, plunger type, overload relays with time-limit fuses.

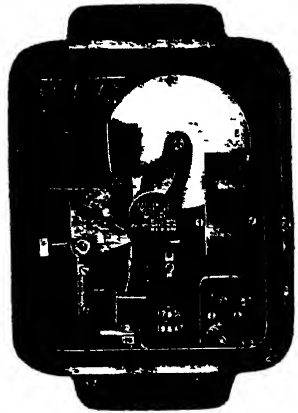


FIG. 244.—Ferranti, single pole, time-limit overload relay (induction type, circuit-opening contacts).

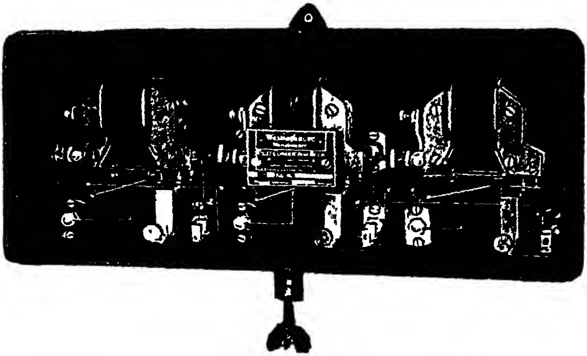


FIG 245.—Metropolitan-Vickers triple-pole relay for leakage protective systems

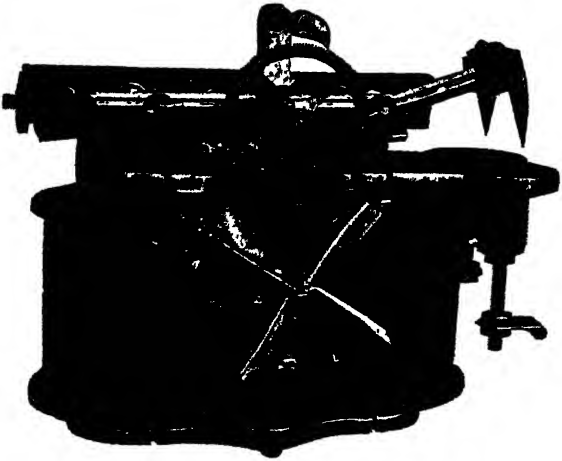


FIG. 246 —Movement of B T-H. reverse-power relay (circuit-closing contacts).

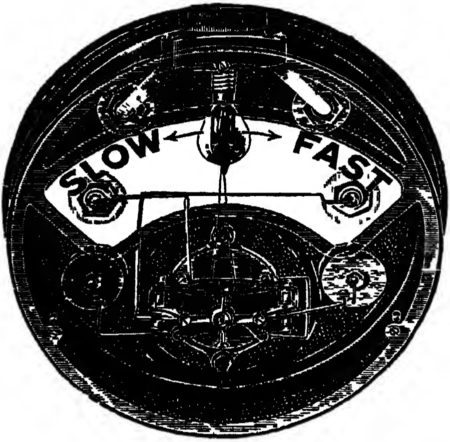


FIG. 247—Phantom view of Weston synchroscope showing fixed and movable coils, pointer and lamp (For connections, *see* Fig 151*A*, p 125)

FIG 248—B T -H. Synchroscope (bipolar motor type)

FIG 249 —B T -H 4-point synchronizing plug and receptacle

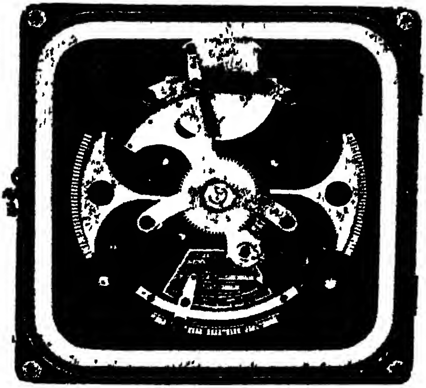


FIG 250 —Brown-Boveri automatic voltage regulator for A C. circuits. (For description and connections, *see* pp. 161–164.)

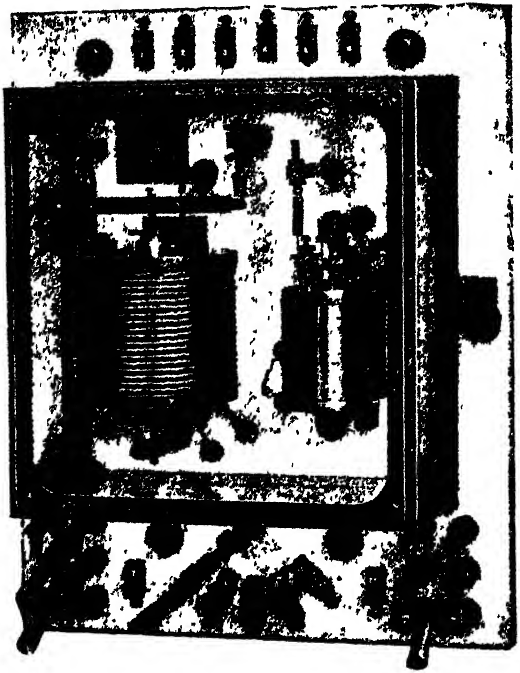


FIG 251—B T-H. Tirrill regulator (Type TD, Form GG) for small D C. generators (For description and connections, *see* pp 158–160)

The control relay is shown to the left, and the differentia relay is shown to the right.

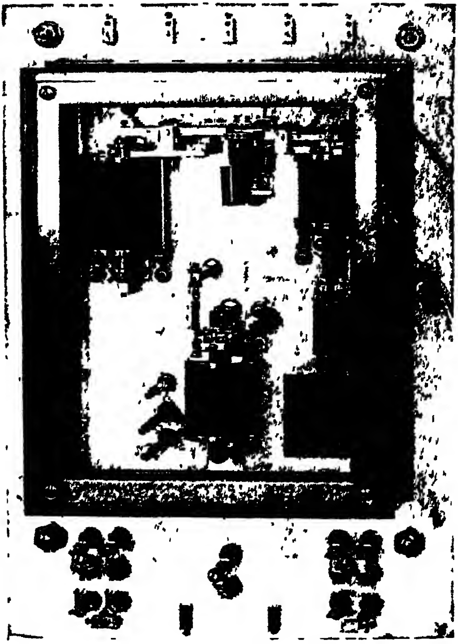


FIG 252—B T -H Tirrill regulator (Type TA, Form AA2) for A C machines (For description and connections, *see* pp. 158–160)

The regulator illustrated is suitable for controlling one alternator with its exciter The control relay occupies the upper portion of the case—the exciter control solenoid being to the left, and the main control solenoid to the right—while the differential relay occupies the lower portion of the case

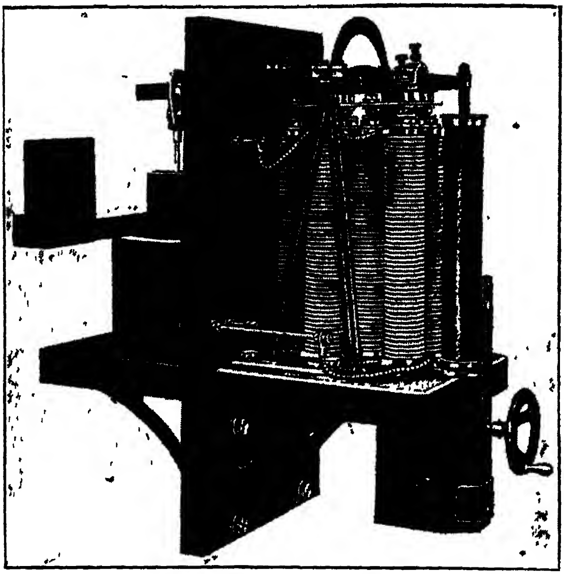


FIG 253—Carbon-pile regulator for controlling "Entz" automatic reversible booster [The Chloride Electrical Storage Co]

The operating solenoid, with its suspended plunger and one of the bus-bar connections, is shown mounted on the bracket at the back of the panel The handwheel controls the tension of the spring (enclosed in the tube) which balances the pull of the solenoid Thus the (generator) load for which the booster is regulated can be adjusted to suit the number of machines running

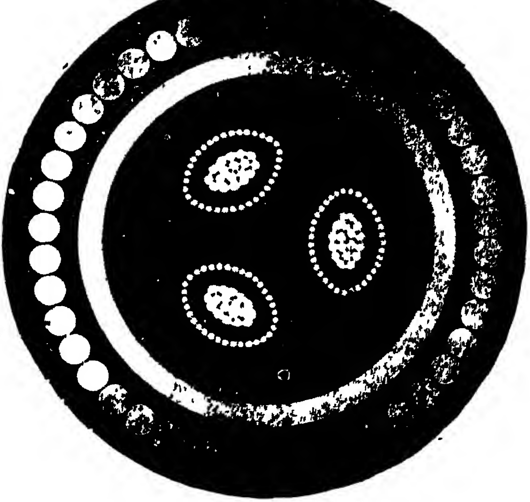


FIG 254 —Full-size, cross-sectional, view of split-conductor cable, supplied by Messrs. W. T Henley's Telegraph Works Co. to the North-East Coast Electric Supply Co.

Specification.—0 1 sq in, three-core, split-conductor cable, insulated with impregnated paper, with jute wormings between cores, sheathed with a solid drawn tube of pure lead, served with two coats of Hessian tape, armoured with a layer of galvanized steel wire, again served with two coats of Hessian tape, finished with compound and tarred For a working pressure of 6,000 volts

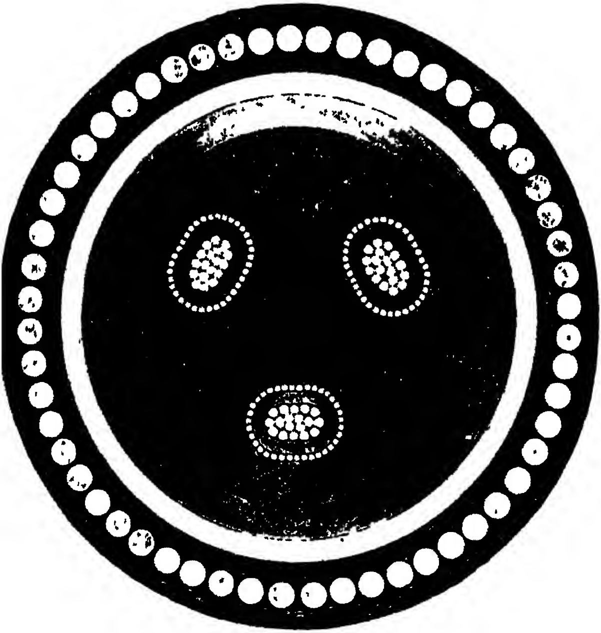


FIG 255 —Full-size, cross-sectional, view of 0·1, sq in , 20,000 volt, split conductor cable, supplied by Messrs W T Henley's Telegraph Works Co to the Buenos Ayres Western Railway (Suburban lines electrification) [1]

Specification is similar to that for the 6,000-volt cable on p 201 Working pressure 20,000 volts.

[1] Messrs Henley have informed the author that they have supplied 115,800 meters (72 miles) of this cable to the B A W.R

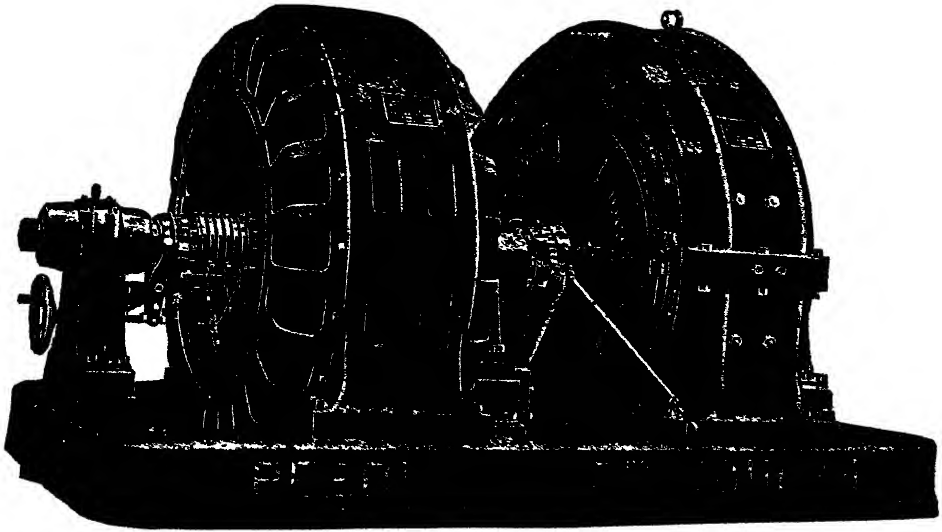


FIG 256.—2,500 kW Peebles motor converter.

FIG 257 —Peebles 500 *kW* motor converters in industrial works substation The starting gear is shown in the foreground (For connections, *see* Fig 188, p 153)

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